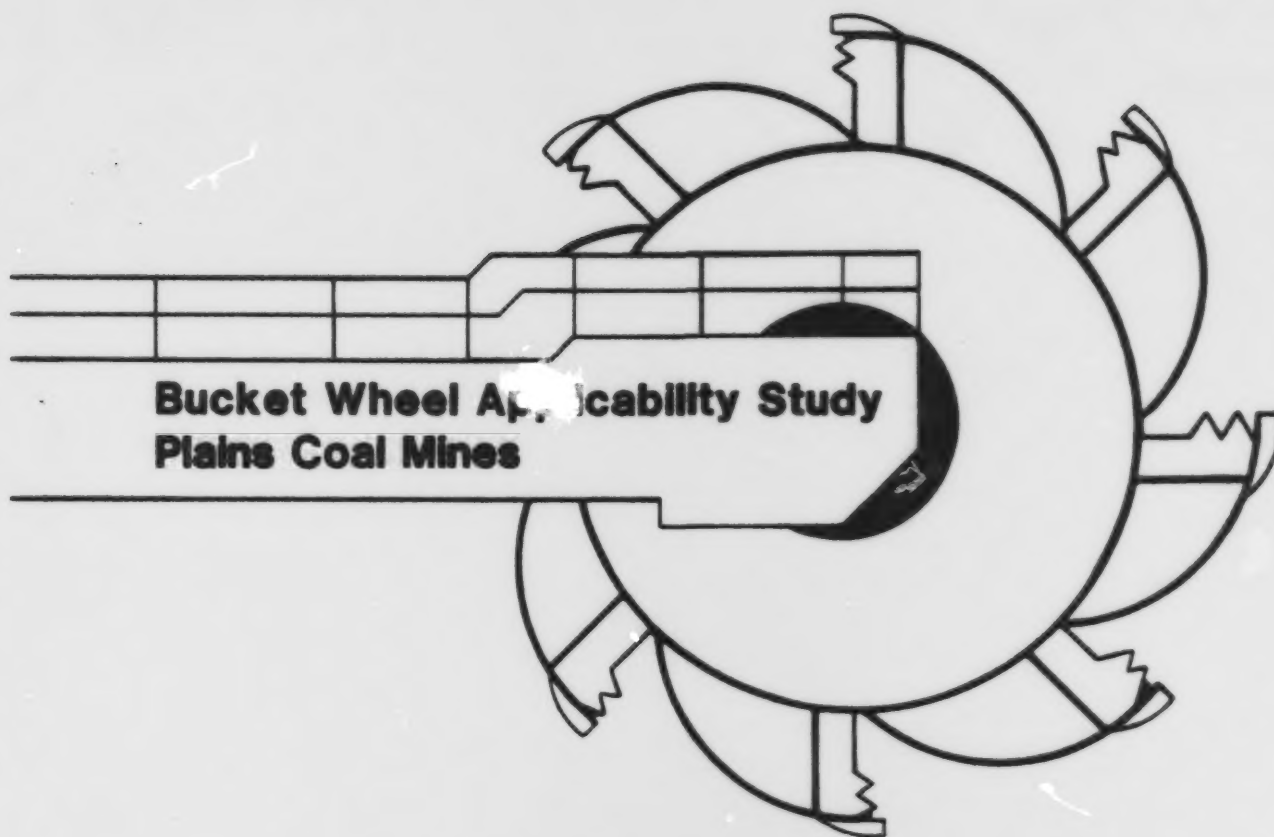




**Bucket Wheel Applicability Study
Plains Coal Mines**

**Prepared for:
Department of Energy, Mines
and Resources (CANMET)**

**March 1981
North American Mining Consultants Ltd
and
Geocon (1975) Ltd**

DEPARTMENT OF ENERGY, MINES AND RESOURCES

CANMET

BUCKET WHEEL APPLICABILITY STUDY

PLAINS COAL MINES

MARCH 1981

NORTH AMERICAN MINING CONSULTANTS LTD.

AND

GEOCON (1975) LTD.

90-00174/

CONTRACT SERIAL NUMBER OSQ80-00065

CONTRACT REQUISITION NUMBER 23440-9-9148

CONTRACTOR: NORTH AMERICAN MINING CONSULTANTS
LIMITED

THE PURPOSE OF THIS STUDY IS TO IDENTIFY THE CHARACTERISTICS OF
OVERBURDEN IN ALBERTA AND SASKATCHEWAN PLANS COAL FIELDS WHICH
WOULD LIMIT THE APPLICATION OF BUCKET WHEEL EXCAVATORS.

WRITTEN FOR: DEPARTMENT OF ENERGY, MINES AND RESOURCES,
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Work on this project was conducted under the auspices of the
Canada Centre for Mineral and Energy Technology, Energy, Mines
and Resources, Canada.

154pp

DDS FINE NUMBER: 17SQ.23440-9-9148

DDS CONTRACT SERIAL NUMBER: OSQ80-00065

CANMET PROJECT NUMBER: 334103

DATE: March 1981

MICROMEDIA

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1.0 INTRODUCTION

Over the last several years Canada Centre for Mineral and Energy Technology (CANMET) has taken the initiative to introduce new technology to the mining industry in Canada. Projects initiated by CANMET have added significantly to the state of the art of mine safety, waste disposal, reclamation and economic evaluation. This project, concerning the applicability of the bucket wheel excavator in plains coal mines, makes a valuable scientific and technical contribution to a poorly understood subject.

This report should be read in conjunction with three earlier documents. The first report: Materials Handling Methods for Plains Coal Mines* (1977) is a comprehensive review of mining methods and equipment applications in coal strip mines in Alberta. It includes excellent illustrations of typical geological conditions in the Diplomat, Forestburg South (Paintearth), Vesta and Sheariness Mines. The application of draglines and other support equipment is studied in detail providing the reader with a thorough understanding of the materials handling problems involved. The report was prepared by Techman Ltd., and Rheinbraun-Consulting Inc. for Alberta Environment and Coal Association of Canada.

A major recommendation of the Materials Handling Methods for Plains Coal Mines report was to study the application of cross-pit conveyors. In 1979 the Coal Mining Research Centre (CMRC) in Edmonton authorized SNC/TOTTRUP Services, Ltd., and Krupp Industries (Canada) Ltd. to study the feasibility of cross-pit conveyors. The report: Cross-Pit Conveying

Systems Study (1980)* presents various design possibilities for such systems as well as their associated costs.

Since neither of these reports addresses the specific problems of excavating the various geological formations present, CANMET initiated an overview report for the specific purpose of evaluating this aspect of the problem. The report: Potential of Bucket Wheel Technology for Mining Plains Coal (1979) was internally prepared by Mr. Val Srajer, a senior engineer with CANMET.

The report begins with a listing of the major equipment in use in larger operating plains coal mines. It contains a major chapter on basic bucket wheel operating methods and a table which summarizes the geological conditions in mines in which bucket wheel excavators are operated. An important part of this document is an appendix reviewing bucket wheel applications in North America, Europe, Asia and Australia. The types of bucket wheel excavators and the necessary support equipment employed in each mine is stated.

This CANMET report helped to place the potential of bucket wheel applications into a Canadian perspective and led, in due course, to the awarding of a project designed to test geological conditions in Canadian mines to North American Mining Consultants Ltd. (NAMCO) in Toronto and GEOCON (1975) LTD. in Calgary. Rheinbraun- Consulting, a partner in NAMCO, was assigned the responsibility of managing the project. GEOCON (1975) LTD. was subcontracted by NAMCO to establish the geological conditions and test field samples in its laboratory. The final report was jointly prepared by Rheinbraun-Consulting and GEOCON staff.

* See Reference List in Appendix I.

The next several paragraphs, taken from the contract, introduce the project and put it into perspective in terms of CANMET's scientific programs.

1.1 Background

The bucket wheel excavator has received little attention in Canadian mining mainly because domestic and U.S. equipment manufacturers have opted to increase unit capacity by increasing the size of the more conventional shovels and dragline excavators.

High productivity, versatility, plus their ability to lay down spoil in the same sequence as before mining, economy, continuous operation and adaptability to most types of haulage make bucket wheel excavators potentially attractive as prime excavators of low grade ores, tar sands, coal and for stripping overburden. Because of its continuous operation and simplicity, the operation of the bucket wheel excavator can be mathematically modelled and simulated by a computer, thus providing estimates of its productivity for a given set of operating conditions.

Initially the intent is to establish guidelines by which a mine operator can determine the applicability of a bucket wheel excavator to a specific situation. One of the prime factors affecting the applicability of a bucket wheel excavator to a particular operation is the determination of overburden characteristics. This is probably the most critical variable in determining the limitations and applicability of bucket wheel excavators.

1.2 Objectives

To identify characteristics of overburden in Alberta/Saskatchewan Plains Coal fields that would limit application of bucket wheel excavators.

Work Statement:

1. Review experience with bucket wheel mining systems and identify those factors critical to application in Alberta/Saskatchewan plains coal fields.
2. Identify standard tests and overburden exploration necessary to apply bucket wheel excavators to plains coal fields.
3. Review pertinent geological, hydrogeological, topographical and climatic information on these plains coal fields most applicable to continuous mining systems.
4. After evaluating the review, identify appropriate overburden components and evaluate cutting resistance factors. The contractor will visit typical surface mine sites in plains coal fields, and will collect samples of overburden material for laboratory testing. It is expected a large number of samples will be collected in the field. Testing method will be that developed by Orenstein and Koppel (O&K) Germany by measuring the penetration resistance of the bucket tooth to the soil. The cutting resistance values from laboratory will be compared with theoretical values determined by calculating tangential cutting force of the wheel. The cutting

resistance of selected overburden material will be the resistance to digging in relation to the length of effective cutting edge (kilogram force/centimeter of cutting length).

5. Specify areas of mining properties most favourable to bucket wheel mining; present tables showing relation between soil types of unexcavated material and cutting resistance factor, indicate areas applicable to continuous mining systems, areas applicable to bucket wheel mining with limitations and areas not suitable for bucket wheel mining. The limitations must be explained.

1.3 Acknowledgement

This project could not have been possible without the generous cooperation of the owners and operators of the mines which were visited by the consultants. The consultants acknowledge the cooperation of the following companies:

Calgary Power Ltd.
Saskatchewan Power Corporation
Luscar Ltd.
Manalta Coal Ltd.

The support of the Energy Resources Conservation Board of Alberta and the Department of Geology and Mines of Saskatchewan in supplying data on coal mines and fields is greatly appreciated.

Finally, we would like to express our appreciation to Mr. Val Srajer of Canmet for his generous support.

2.0 DESCRIPTION OF FIELD PROGRAM

Rheinbraun and Geocon staff, accompanied by Mr. V. Srajer of CANMET, visited six mines: Whitewood and Highvale on October 7; Diplomat and Roselyn on October 14; and Poplar River and Souris Valley on October 21 and 22, 1980. These mines represent a good cross-section of geological formations with only two major exceptions: the Vesta and the Forestburg South (Paintearth) Mines. The inclusion of these mines would have completed the cross-section. It is hoped that these mines will be included in future sampling programs.

Upon arrival at the mines discussions were held with the mine managers to acquaint them with the project and the sampling objectives. The mine managers took the sampling personnel on a tour of the mine areas of interest and provided them with information on the existing rock types, the operations of the mines, and the most suitable sampling locations.

Samples were obtained from the pit excavations following an initial assessment of the rock strata at each mine. Representative samples were collected from talus at the base of the slopes, and then oriented to the stratigraphic section seen on the pit wall faces. The samples were labelled and wrapped in plastic for transport to the laboratory.

The sampling procedures emphasized the collection of rock types suspected to be marginal in terms of excavation with bucket wheel excavators. Actually, in all cases the rocks sampled were the hardest materials that were observed by the field engineers. Samples were not taken at the Whitewood and Roselyn Mines because it was concluded that all of the mater-

ials present could be handled efficiently by bucket wheel excavators. A total of eighteen samples were obtained; six from the Highvale Mine, two from the Diplomat Mine, and five from each of the Poplar River and Souris Valley Mines.

During February, 1981, CANMET staff obtained frozen samples from three of the mines. The samples were transported frozen in insulated containers to a cold room at the Geocon laboratory.

3.0 GEOLOGICAL OVERVIEW OF PLAINS COAL MINING REGION

The main physiographic regions, or geological provinces, of Western Canada are the Shield, the Interior Plains and the Cordillera. The limits of these regions are shown on Figure 1. The topography of the Shield is ancient while the bedrock of the Interior Plains is geologically young. The Cordilleran Region is characterized by rugged terrain and the bedrock varies from young to ancient.

Coal bearing strata are found in both the Cordillera and Interior Plains Regions. The objective of this study was to gather data from operating coal mines within the Interior Plains Region to provide the basis for an assessment of the applicability of utilizing bucket wheel excavator technology for open cast coal mining.

Within the study area the land surface is generally level to gently undulating. Elevations range from approximately 1200 metres a.s.l. in the west, to about 750 metres a.s.l. in the east. Surficial glacial drift varies in thickness from a few centimetres to 100 metres or more. The underlying bedrock varies in lithology from lacustrine to marine clastic sediments. The bedrock is generally less than 100 million years old. A simplified map of the bedrock geology and the mine locations is shown in Figure 2.

The various bedrock units, and the coal bearing zones contained within the bedrock units, are continuous over large portions of the study area.

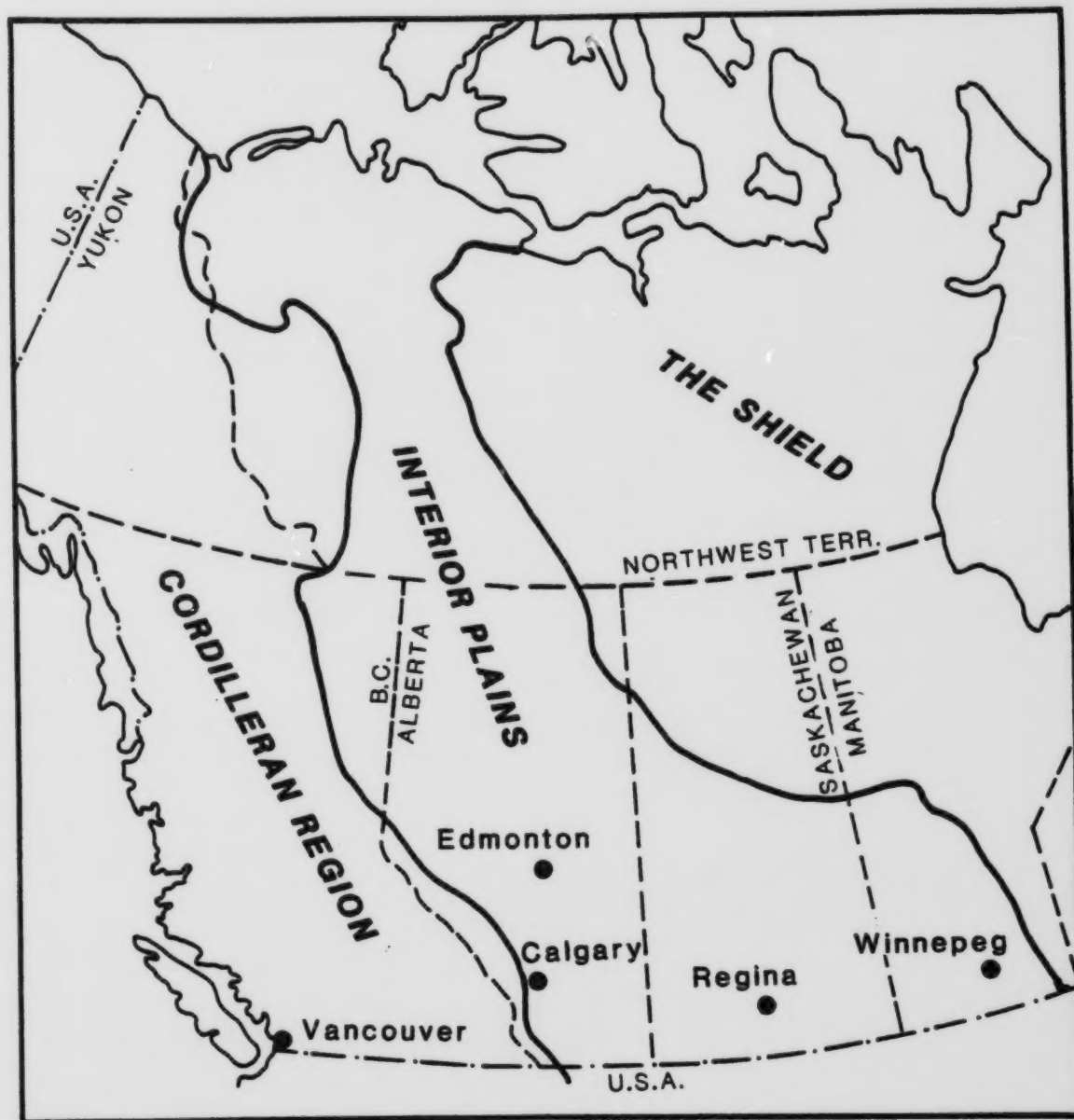


FIGURE 1: PHYSIOGRAPHIC REGIONS OF WESTERN CANADA

(after Douglas, 1970)

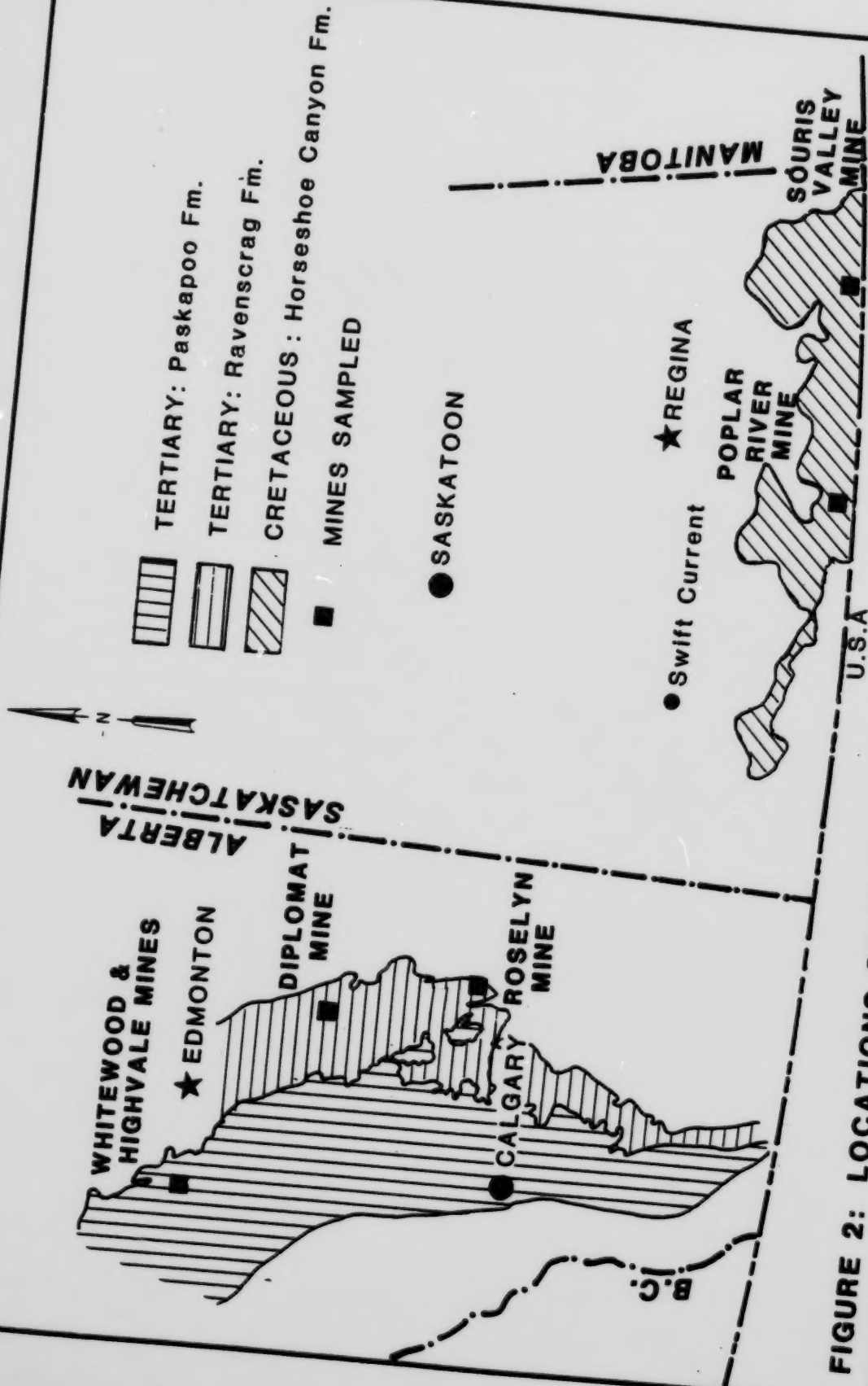


FIGURE 2: LOCATIONS OF TEST MINES WITHIN MAJOR STRATIGRAPHIC UNITS

The bedrock strata are generally flat-lying to gently dipping except where locally disturbed by glacio-tectonic mechanisms. In Alberta coal bearing strata are found within the Upper Cretaceous Horseshoe Canyon, Oldman and Foremost Formations, and in the Cretaceous/Tertiary Paskapoo Formation. The most prolific occurrences of coal in Saskatchewan are within the Tertiary Ravenscrag Formation, in the southeastern part of the Province. The mines included in this study were located in the Horseshoe Canyon, Paskapoo, and Ravenscrag Formations. Table 1 displays the geological correlations between the individual mines in this study.

The coal fields included in this study are shown in Figure 3. The gross lithologies of the overburden strata are similar in all six mines which were studied. Dominant rock types are sandstone, siltstone and claystone. Within these types, significant variations in texture, bedding thickness, geologic discontinuities, and mineralogy can be observed. Almost all of the bedrock which was examined is classified as compacted (or "cemented" with fine grained material), while the hardest strata are cemented in the true sense, usually by carbonate minerals. The bedrock is poorly indurated for the most part. Generalized sections of the mine stratigraphy are included in the individual mine descriptions.

Most of the bedrock strata at the six mines have engineering properties between those of a "true" soil and rock. Geotechnical engineering studies have probably been performed for each of the mines studied, however such studies are proprietary. The physical properties of each geological formation may also vary quite widely. For example, coal seams in the Ravenscrag Formation are mined from similar lithologies at

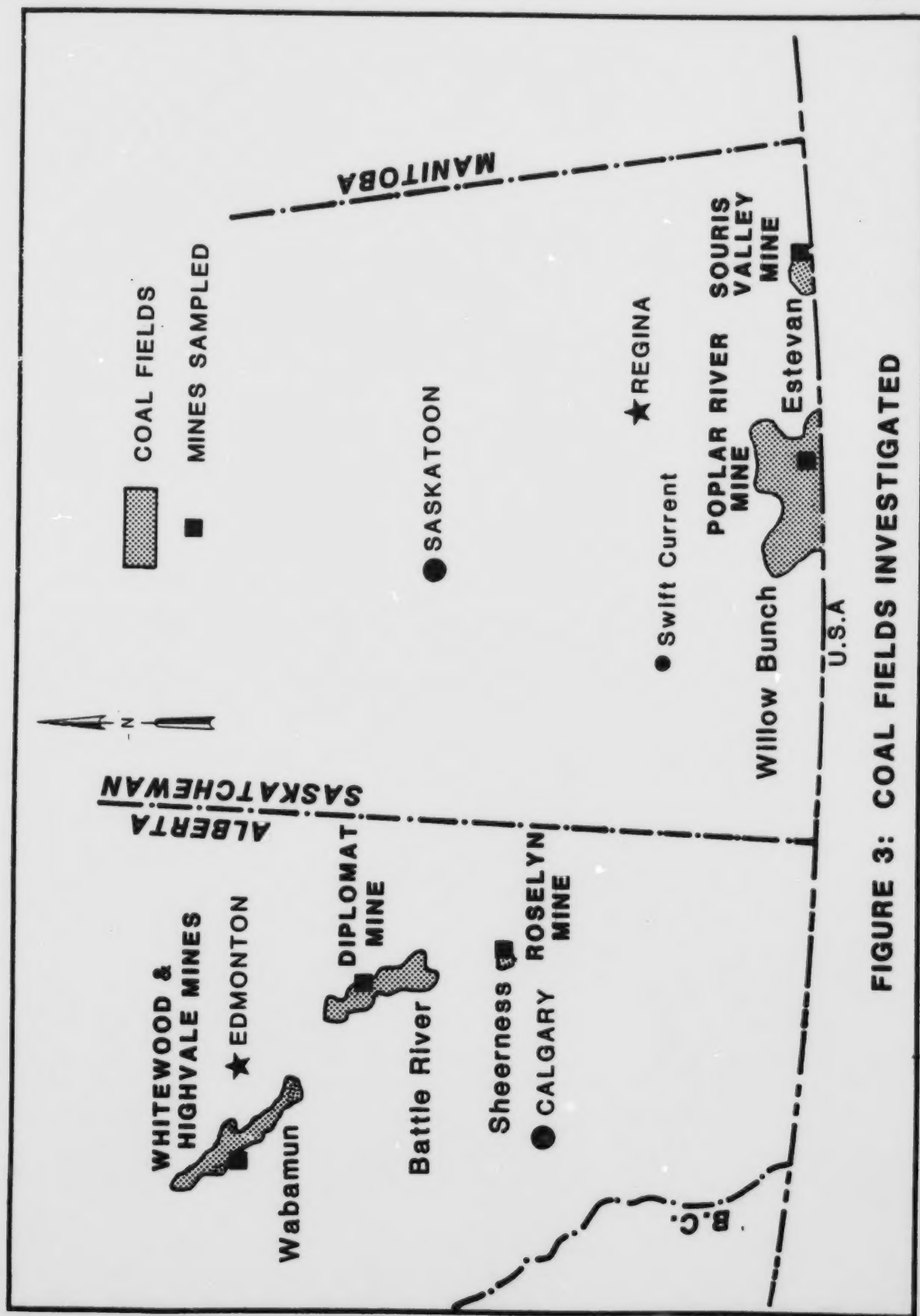


FIGURE 3: COAL FIELDS INVESTIGATED

the Poplar River and Souris Valley Mines, but the highwalls of the same height were observed to be stable at angles of 35° and 70° respectively. Highwall stability is, of course, also dependent on several other variables such as groundwater, topography, structure, and geological discontinuities.

The material types present at and surrounding each mine are shown on the maps included in Appendix VII.

4.0 DESCRIPTION OF MINES VISITED

4.1 Climate

The climate of the study area varies from subhumid in the north to subarid in the south. Yearly average precipitation across the region is in the order of 300 to 500 mm, while the average annual potential evapotranspiration is 500 to 550 mm. The average number of frost free days varies from 100 to 120 at the studied mines. Greatest temperature range is about -40° C to +33° C. Frost penetration up to 2.4 m may occur on faces which are exposed for longer periods of time. At mines with progressive removal of overburden over the entire exposed surface the frost penetration on active faces is reduced and sometimes eliminated. Freezing may occasionally cause local build-up of ground water pore pressure and icing conditions on pit walls.

4.2 Whitewood Mine

The Whitewood Mine, located 75 km west of Edmonton, is owned by Calgary Power Ltd. and operated by Manalta Coal Ltd. The coal production of about 2 million tonnes annually is supplied to the Wabumun Generating Station. The coal is subbituminous B with a heating value of 19 MJ/kg (8000 BTU/lb), has a moisture content of 25%, and an ash content of 11%. The coal is mined from the Scollard Member of the Paskapoo Formation. There are five coal seams with an aggregate thickness of 3 to 7 metres. A generalized section in the east pit is as follows:

<u>Depth, m</u>	<u>Material</u>
0 to 2.5	peat (muskeg)
2.5 to 3.5	clay
3.5 to 4.5	silt till
4.5 to 12.5	gravel and sand
12.5 to 20.0	coal and interburden

The overburden ranges between 10 and 30 metres in thickness. The extensive overlying peat deposits are dewatered with surface ditches prior to mining. The upper coal seam is the major aquifer with regional flow towards the south. Water entering the pits is collected in sumps. The ground water flow is intercepted by a deep cut-off trench which has been constructed north of the mining area.

The gravel and sand overburden is stockpiled for future commercial use. The strata in the mine area dip gently westward, however in some areas glaciotectionic mechanisms have resulted in variable overburden depths and folded and undulating coal seams (Figure 4, Photo 1).

Failures in both highwall and spoil piles necessitate double handling by the mine equipment, particularly in the north pit (Figure 4, Photo 2). Two draglines are used for stripping, a 25 cubic metre Ransomes Rapier and an 8 cubic metre Marion. Partings and coal seams are removed with loading shovels and miscellaneous mobile equipment.



PHOTO 1 Note low amplitude folds in coal and partings;
also gravel overburden which is stockpiled.

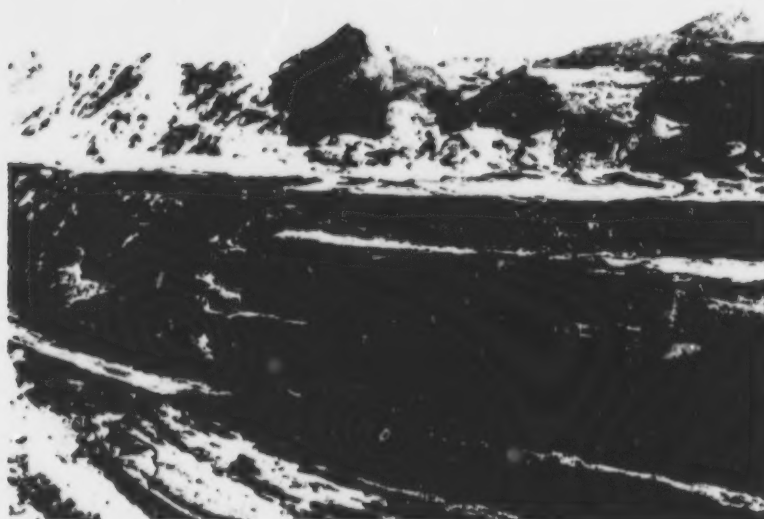


PHOTO 2 Note slope failure in North Pit; also dewatering
lines in foreground.

Figure 4 WHITEWOOD MINE

4.3 Highvale Mine

The Highvale Mine is located 10 km south of the Whitewood Mine. This mine is also owned by Calgary Power Ltd. and operated by Manalta Coal Ltd. The yearly production of approximately 6 million tonnes is utilized at the Sundance Generating Station. The coal is obtained from the Scollard Member of the Paskapoo Formation with coal properties similar to the coal mined at the Whitewood Mine. There are four economically mineable seams with an aggregate thickness of 5 to 12 metres. The coal seams are flat lying.

In the western part of the mine the overburden is about 15 metres thick and the following illustrates a typical section (Figure 5, Photo 3).

<u>Depth, m</u>	<u>Material</u>
0 to 4	silty till
4 to 8	claystone and siltstone
8 to 9	siltstone (cemented)
9 to 13	claystone and siltstone
13 to 15	siltstone (cemented)
15	coal

The two beds of hard, cemented siltstone are ripped with dozers prior to stripping. The extent of the harder, more indurated strata is not known. The overburden is generally thinner (10m) in the eastern part of the mine.

In the western part of the mine spoil pile failures have occurred on several occasions (Figure 5, Photo 4), usually in areas where the overburden is thickest. In this area the

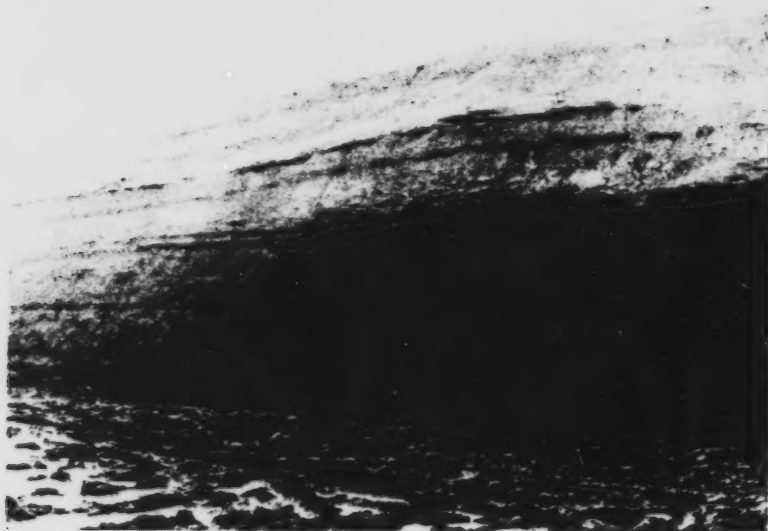


PHOTO 3 Typical section western part of mine: note the two, hard, resistant siltstone beds.

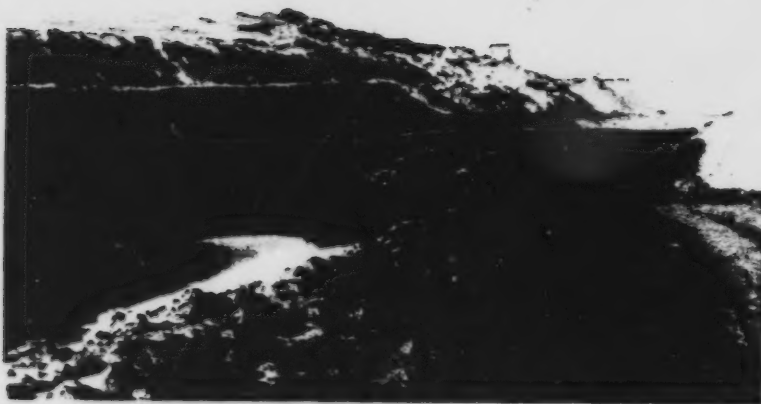


PHOTO 4 Highwall failure western part of mine where overburden is thickest.

FIGURE 5 HIGHVALE MINE

till is now prestripped and the dragline operates on the bed-rock surface. The most unstable areas are being bypassed at the present time and it is tentatively planned to use a two bench dragline mining scheme.

A Marion dragline with a 23 cubic metre bucket is being used to remove the overburden. Coal seams and partings are removed with 6 cubic shovels and mobile equipment.

4.4 Diplomat Mine

The Diplomat Mine is located approximately 140 km southeast of Edmonton, near Forestburg, Alberta. Most of the yearly production of about 700,000 tonnes is supplied to the Battle River Generating Station. The mine is owned and operated by Forestburg Collieries Ltd. (Luscar Ltd.). Subbituminous B coal is extracted from the Battle River coal seam in the Horseshoe Canyon Formation. The coal has a heating value of 20 MJ/kg (8600 BTU/lb), a moisture content of 24% and an ash content of 7%.

Overburden varies in thickness from 7 to 12 metres. A typical section observed at the pit face was as follows:

<u>Depth, m</u>	<u>Material</u>
0 to 5	silty till
5 to 8.5	silty till (very stiff to hard)
8.5 to 11.5	coal

In other areas of the mine there are also poorly indurate bedrock strata overlying the coal seam. The coal seam is relatively flat lying.

Topsoil is prestripped and stockpiled by scrapers. Then the overburden is removed with a 23 cubic metre shovel and an 8.5 cubic metre dragline. Coal is excavated by two 7.5 cubic metre shovels and mobile equipment. All material is relatively soft and blasting or ripping is not required.

4.5 Roselyn Mine

The Roselyn Mine is located 170 km northeast of Calgary, Alberta and is owned and operated by Manalta Coal Limited. In recent years most of the yearly production of about 350,000 tonnes was supplied to the Saskatchewan Power Corporation. In the near future the Sheariness Coal field will be developed on a larger scale to provide coal to the proposed Sheariness Generating Station. The following is a typical highwall section.

<u>Depth, m</u>	<u>Material</u>
0 to 1.0	silty till
1.0 to 2.5	claystone and siltstone
2.5 to 3.0	oxidized coal
3.0 to 6.0	claystone and siltstone (bentonitic)
6.0 to 8.0	coal

At the present time stripping is carried out using a shovel and mobile equipment.

4.6 Poplar River Mine

The Poplar River Mine supplies in the order of 2 million tonnes of coal per year to the Poplar River Generating Station, owned by the Saskatchewan Power Corporation. The lignite is mined from the Hart Seam of the Ravenscrag Formation. The coal has a heating value of 12 MJ/kg (5,000 BTU/lb), a moisture content of approximately 35%, and an ash content of about 12%. The mine is 145 km south of Moose Jaw, Saskatchewan.

The Hart Seam is relatively flat lying and is in the order of 3.3 to 4.5 metres thick in the mine. In some areas of the mine there is a 1 metre thick parting which splits the seam. The overburden thicknesses are variable and a typical section is as follows:

<u>Depth, m</u>	<u>Material</u>
0 to 13.5	brown, gravelly, and silty till
13.5 to 16.5	sandstone and siltstone
16.5 to 19.5	claystone and siltstone
19.5 to 23.5	coal

The coal seam is the primary aquifer with some seepage also encountered in the coarser-grained, upper portions of the bedrock. Regional flow is towards the southeast. Large diameter wells have been constructed to the northwest of the mine and the dry pit floor indicates that the dewatering system is generally effective. However, where the parting is present, the portion of the coal seam below the parting has not been as effectively dewatered. It is planned to mine the

coal in these areas using backhoe equipment and sump drainage.

A Bucyrus-Erie dragline with a 69 cubic metres bucket is used to strip the overburden and a 12 cubic metres Bucyrus-Erie loading shovel is used to recover the coal.

The mine has experienced two types of slope instabilities:

a) Highwall failures: The mine personnel have rectified this problem by step-benching the highwalls to an angle of 1.5 horizontal to 1 vertical (34°). One highwall failure, which was observed during the trip occurred in the till, and appeared to be controlled by well developed vertical jointing in the till. Water seepage near the base of the slope also likely contributed to the highwall failure (Figure 6, Photo 5).

b) Spoil pile failures: Circular arc-type soil movements have occurred in the spoil piles. Limited observations suggest that steep spoil slopes and/or the placing of wet spoil material have likely caused the failures (Figure 6, Photo 6). Both types of slope failure have required rehandling of material.

4.7 Souris Valley Mine

The Souris Valley Mine, owned and operated by the Saskatchewan Power Corporation, is located 5 km south of Estevan, Saskatchewan. The production of the mine is about 400,000 tonnes



PHOTO 5 Highwall failure in vertically jointed till;
note benched highwall.



PHOTO 6 Spoil pile failure covering coal seam.

FIGURE 6 POPLAR RIVER MINE

of lignite coal per year which is supplied to the Boundary Dam Generating Station. The properties of the coal are similar to those at the Poplar River Mine.

The coal is mined from the Estevan Seam of the Ravenscrag Formation. In some areas of the mine the seam is split by a parting about 1 metre thick. The combined thickness of the Estevan Seam is about 3.5 metres.

The highwalls are excavated at an angle of about 70° and the overburden is approximately 16 metres thick. The upper 2 to 4 metres is till interspersed with boulders of various sizes. This till is underlain by sandstone, siltstone and claystone (Figure 7, Photo 7). In some areas the claystone near the base is relatively well indurated and is cemented by calcite. The coal seam is generally flat. However, in some areas there are gentle, low amplitude folds (Figure 7, Photo 8). A typical stratigraphic section is as follows:

<u>Depth, m</u>	<u>Material</u>
0 to 3	bouldery, silty till
3 to 14	claystone and siltstone
14 to 15	claystone (indurated)
15 to 16	claystone and siltstone
16 to 19	coal

Overburden stripping is carried out with a 10 cubic metre dragline and the coal is loaded onto trucks with a 4 cubic metre loading shovel. In some areas of the mine dozers must rip the cemented claystone prior to dragline handling.



PHOTO 7 Typical highwall section; overburden about 16m thick.

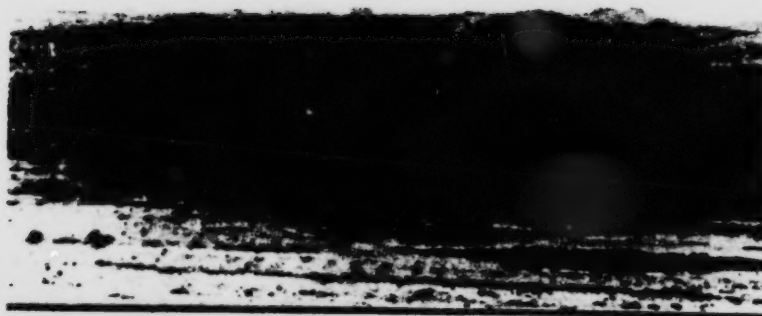
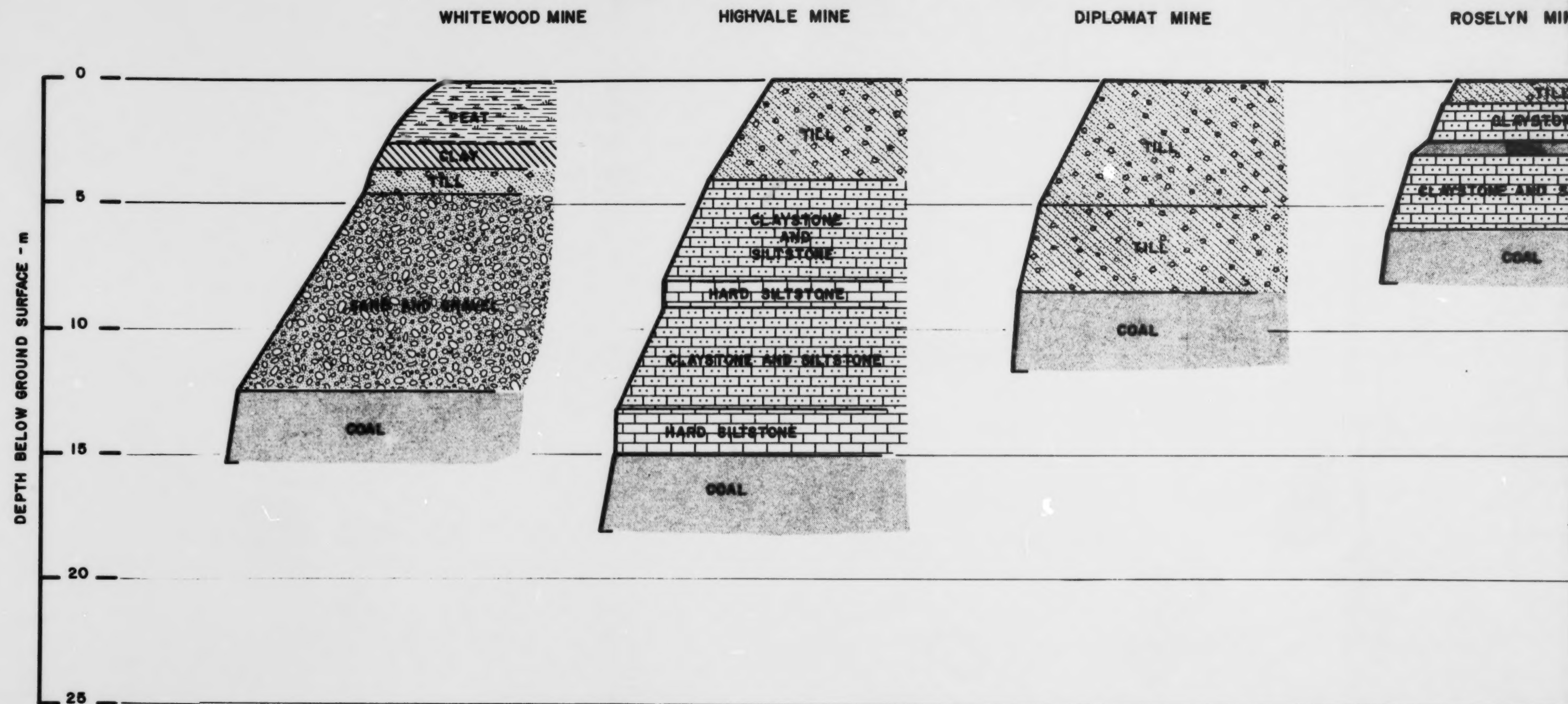


PHOTO 8 Note low amplitude folding in coal seam.

FIGURE 7 SOURIS VALLEY MINE

Figure 8 shows the generalized stratigraphic section representative of each of the mines that was examined during the study.



DIPLOMAT MINE

ROSELYN MINE

POPLAR RIVER MINE

SOURIS VALLEY MINE

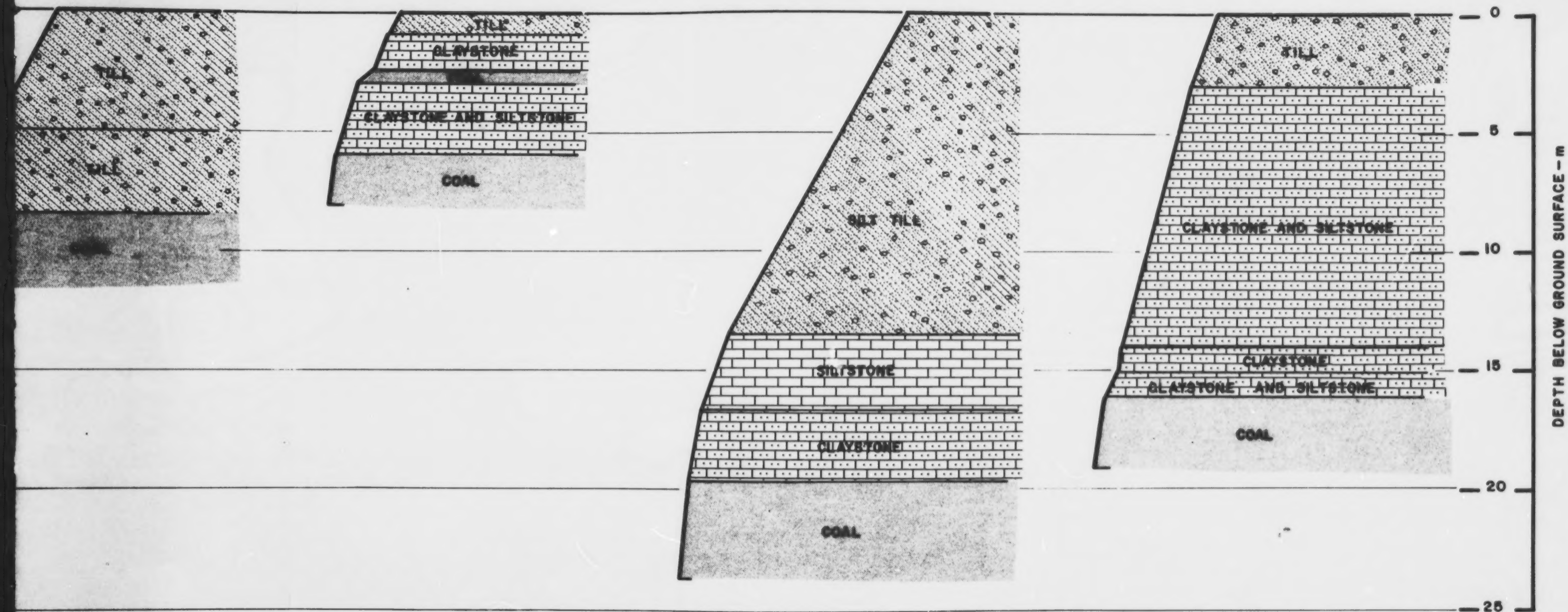


FIGURE 8
STRATIGRAPHIC PROFILES
IN TEST MINES

5.0 GEOLOGICAL DATA REVIEW

Numerous documents in the public domain were examined in order to assess the geological conditions at each mine area. The available literature ranged from promotional material prepared by the mine companies to papers in technical journals, and government sponsored studies on regional geology of Western Canada.

The majority of the "hard" data was obtained from exploration drill hole information provided by Alberta and Saskatchewan government agencies. The records center at the Alberta Energy Resources Conservation Board provided non-confidential exploration hole records. A great deal of the information which would have been useful to the study if confidential, particularly in the vicinity of the Whitewood Mine. The department of Geology and Mines, Saskatchewan Mineral Resources, provided exploration records for the Souris Valley and Poplar River Mines. Information gleaned from the various documents was supplemented by observations made at the mine sites. The data was subsequently collated, interpreted, and used for the preparation of the maps presented in this report.

Most, if not all, of the information which is available for the mines is not directly applicable to mine equipment evaluation, particularly the determination of cutting resistance. The rock material descriptions are based on geological characteristics, that is descriptions of particle size and index properties. The purpose of the drilling programs was obviously the delineation of the extent of the coal bearing

strata and little emphasis was placed on describing the strata above or within the coal horizons.

Descriptive terminology used in reports also varies quite widely. In compiling the overburden type ratio maps some interpretation of terminology between data sources was necessary. Most of the lithological descriptions are based on chip samples.

The physical character of the rock types is not discussed in any detail in the published information. Where a description is provided, the descriptions of physical rock properties, for example hard or soft, are not accompanied by any type of quantitative relationship. The literature does not contain numerical values for the properties of the rocks, e.g., rock quality designations or compressive strengths. Thus the help of mine managers at the respective mines who gave information freely on the rock characteristics and their operational problems with hard or otherwise difficult strata was much appreciated.

Included in Appendix I are the major references which were used for this study.

6.0 LABORATORY TESTING

The rock samples selected in the field were irregularly shaped pieces with dimensions in the 25 to 50 cm range. The test specimens were prepared by cutting the field samples with a diamond saw to form cubes. Depending on the sample size, and the presence of planes of weakness, the finished cubes had dimensions of 12 to 17 cm. Thirteen of the eighteen unfrozen samples were of sufficient competence to prepare cube specimens. In comparison nine of the ten frozen samples were cut into cubes.

Unfrozen cutting tests were performed on seven siltstone, one sandstone, two till, and three claystone samples. Frozen cutting tests were performed on five till, three sandstone, and three siltstone samples. All frozen samples were tested in a cold room at -24°C . Two of the samples were of sufficient size, to prepare additional cubes to be tested at -6°C .

The cutting tests were performed according to the standard Orenstein and Koppel specifications included in Appendix III. For the first cut the specimens were loaded normal to the orientation of the sample in situ. The photographs on Figure 9 show the details of the laboratory apparatus. Detailed lithologic descriptions of the samples are included in Appendix II.

The complete laboratory test record for each test performed and the physical properties of each sample are provided in Appendix IV. The results from each cut, up to a maximum of 5, are reported in terms of:

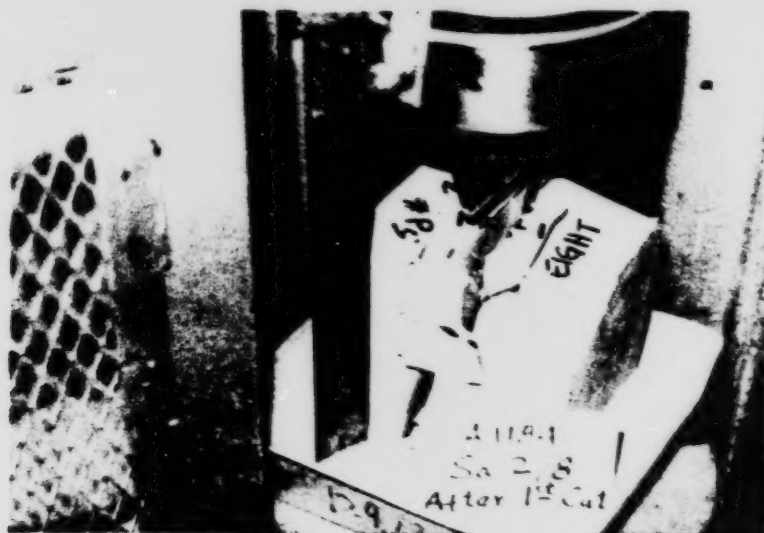


PHOTO 9 Laboratory apparatus set up.



PHOTO 10 Sample after three test cuts.

FIGURE 9 LABORATORY TESTING

F/Ls - force per unit of blade length, N/cm
 F/L - force per unit of separation length, N/cm
 F/A - force per unit of separation area, N/cm²

Among the unfrozen samples the siltstones found in the Highvale Mine exhibited the highest strengths ranging from 356 N/cm² to 993 N/cm². A single sandstone sample in the Highvale Mine exhibited a very low strength of only 16 N/cm².

The next hardest materials were found in the Souris Valley Mine. One sample of claystone exhibited a strength of 880 N/cm² which is very close to the strongest materials tested in the Highvale Mine. Two other samples had considerably less strength: 161 and 111 N/cm².

The siltstones and the silty tills from the Poplar River Mine and the Diplomat Mine exhibited rather low strengths: 14 to 57 N/cm².

The test results in N/cm² are summarized below:

<u>SILTSTONE (HIGHVALE)</u>	<u>CLAYSTONE (SOURIS)</u>	<u>SILTSTONE (POPLAR)</u>	<u>SILT TILL (DIPLOMAT)</u>	<u>SANDSTONE (HIGHVALE)</u>
356	111*	14*	57	16
410	161*	40	30	
662*	880	40		
993				

Frozen samples from three mines were tested. As expected, a marked increase in the strength required to cut frozen material was observed. The silty till in the Diplomat Mine showed the greatest increase: on the average of 7 fold increase.

Although the siltstones showed only less than a 2 fold increase, these are still the toughest materials tested. A direct comparison between unfrozen and frozen sandstone is not possible due to insufficient number of samples..

The test results in N/cm^2 for the frozen samples is summarized below:

<u>SILTSTONE</u> <u>(HIGHVALE)</u>	<u>SILTSTONE</u> <u>(DIPLOMAT)</u>	<u>SILT TILL</u> <u>(WHITEWOOD)</u>	<u>SANDSTONE</u> <u>(HIGHVALE)</u>
562	184	250	254
708	428	295	287
1117		366	528

Commentary regarding the cutability of these materials by a bucket wheel excavator is provided in later sections of this report.

For comparison purposes O&K test results reported by Calgary Power for the Highvale Mine are included in Appendix IV.

7.0 PROCEDURES FOR CUTABILITY TESTING AND TEST INTERPRETATION

Many test procedures have been used in the past to determine cutability. Over the last 25 years about 30 types of tests with various degrees of applicability have been described in literature. There are at least half as many more tests referred to in literature for which there is insufficient information available to evaluate the test.

In the past the motivation for most testing was to resolve a question of cutability arising in a specific geological situation where a "customized" Bucket Wheel Excavator (BWE) was in operation. In most of these cases little attention if any, was given to documenting the geological conditions.

In many instances testing has been conducted on a specific material using a customized procedure or one of a kind test equipment. In literature, one can find descriptions of such tests ranging from laboratory bench tests of small samples to rather large in situ tests in the field. Materials tested range from intact samples to reconstituted materials.

A limited amount of information on cutability has also been obtained by instrumenting the buckets of an excavator and monitoring strains, motor forces and power consumption.

The interpretation or correlation of test results have usually not been attempted due to the lack of common denominators. The two most outstanding deficiencies in conducting and reporting tests are:

- ° poor geological descriptions, and
- ° lack of a common test to provide correlation.

In the literature frequently poor or no geological descriptions and insufficient discussion of sampling is given. It is known that even if two materials show the same strength in a particular test, this does not reflect the overall cutability of this material with a BWE.

The lack of common bench test at this time is due to the fact that a) at the present time a single test cannot evaluate completely all the relevant parameters and conditions necessary for BWE evaluation and b) over the time many BWE operators and designers have developed their own preferred empirical correlations between their selected test and their mine operation experience.

In the future it would be beneficial if the individual operators and designaters included one common test in their other testing. The result of this test could be used to correlate the experiences of the different mines and with time select the best test method(s) to standardize the same tests. It is suggested that the unconfined compression test could be a suitable "common test" for this purpose (see ASTM D 2938-79 in Appendix V).

The unconfined compression test is recommended for the following reasons:

- ° procedure for performing this test has been standardized and is used world wide
- ° a large amount of published data is available

- ° there are numerous test facilities available in many countries to perform unconfined compression tests; and
- ° technicians are more likely to be familiar with this strength test than any other test.

Tests which are used to evaluate the bucket wheel cutability fall into several categories:

- ° compression tests
- ° penetration tests
- ° shearing tests
- ° field tests with cutting tools
- ° instrumentation of excavators

A brief commentary on each class of test follows.

Compression Tests

In the common test a cylindrical sample with two parallel end surfaces is prepared with a length equal to twice the diameter. However, compression tests are also being conducted using samples with various other geometrics. The common aspect of a compression test is that the load is applied to the two parallel surfaces. In this test either the breaking load or a stress-strain relationship with the maximum strength can be obtained. The test is normally conducted in a laboratory.

The compressive strength can be also obtained indirectly from impact or rebound tests such as the rebound of a small weight impacting onto the test surface. Various test tools are commercially available. The advantage of such a test apparatus

is that it is fast, economical, and therefore numerous tests can be conducted on the specimen. This type of test could be particularly suitable for testing freshly exposed faces.

Penetration tests

In these tests the strength or cutability is evaluated from the resistance of the sample to penetration of a particular tool. The O&K wedge test is one of several penetration tests that have found a wider acceptance. In this test a wedge is forced into a cube or cylindrical specimen and load measured upon fracture. Another similar test is a point load strength index test where a roughly spherical sample is squeezed between two conical anvils. There are also several testing tools which measure the strength of material by the penetration of a cone shaped pin into the material under a specified pressure.

Shearing Tests

Shearing tests have the advantage of incorporating aspects of tool friction and rate of cutting into the test results. A variety of such test machines have been designed for testing both strong and weak materials. Often the cutting edges can be easily exchanged or reoriented to develop tool performance curves.

Field Tests With Cutting Tools

The need for researchers to obtain more reliable test results may lead to the use of field testing machines where full scale cutting tools can be evaluated. The disadvantage of

many such ingenious devices has been the lack of mobility. Often the device cannot be placed in the position on the desired test material without considerable effort and expense.

Instrumentation of Excavators

Direct full scale testing of cutting tools on an operating bucket wheel can lead to improvements in design and therefore the productivity of the excavator. If a formation similar to that expected in a new proposed mine can be located in an operating mine, then an opportunity exists to accurately evaluate performance. However, the actual cutting resistance and thus performance of the BWE should also take into consideration the particular overall geological and climatic conditions.

8.0 COMPARISON OF LABORATORY TEST RESULTS AND FIELD CONDITIONS IN PLAINS COAL MINES TO TEST RESULTS OBSERVED IN MINES WORLDWIDE

In Rheinbraun's lignite mines in Germany hard strata are the exception. Whenever and wherever a BWE encounters difficulties in cutting or suffers a substantial loss in output, samples are taken and unconfined compressive strength tests are conducted. Typical test results from one such occasion are provided in Appendix VI. Over the years, a data base has been accumulated and can be used for comparison test results taken from operational and planned mines worldwide. Rheinbraun's data reveal that often a low strength clay, but with great plasticity, can be as great an obstacle to digging with a bucket wheel excavator as hard rock. However cutting resistance values would not indicate so.

The test results presented in this report are grouped into those obtained from the testing of samples from Canadian coal mines, done as part of this project, those from Rheinbraun's German lignite mines, and those from mines worldwide. None of the mines in this latter group are as yet in operation. Statements as to the cutability are, therefore, arrived at by comparison with cutability tests in Rheinbraun's mines.

The test results are given in three tables. Table 2 summarizes the results of testing performed on samples taken from six mines located in Alberta and Saskatchewan. Table 3 provides typical results from tests performed on samples taken over a period of time in several of Rheinbraun's mines. Table 4 illustrates results and cutability projections of samples taken from mines in the U.S.A., Spain, Indonesia and

TABLE 2: SUMMARY OF ROCK CUTTING TEST RESULTS
FOR MINES IN ALBERTA AND SASKATCHEWAN

SAMPLE NUMBER	ROCK TYPE	CONDITION	CUTTING RESISTANCE (N/cm ²)		DIGGABILITY RATING*		
			First Cut	Strongest Cut	1	2	3
Highvale No. 1	Siltstone; cal-careous cement	Unfrozen	258	933	.	.	.X.
Highvale No. 3	Siltstone; cal-careous cement	Unfrozen	366	662	.	.	.X.
Highvale No. 4	Sandstone	Unfrozen	11	16	.X.		
Highvale No. 5	Siltstone; cal-careous cement	Unfrozen	198	410	.	.	.X.
Highvale No. 6	Siltstone	Unfrozen	101	356	.X.		
Diplomat No. 1	Silt till	Unfrozen	15	30	.X.		
Diplomat No. 2	Silt Till	Unfrozen	15	57	.X.		
Souris Valley No. 2	Claystone; cal-careous cement	Unfrozen	156	889	.	.X.	
Souris Valley No. 3	Claystone; cal-careous cement	Unfrozen	111	111*	.	.X.	
Souris Valley No. 4	Claystone; cal-careous cement	Unfrozen	161	161*	.	.X.	
Poplar River No. 1	Siltstone; cal-careous cement	Unfrozen	14	14*	.X.		
Poplar River No. 2	Siltstone; cal-careous cement	Unfrozen	34	40	.X.		
Poplar River No. 3	Siltstone; cal-careous cement	Unfrozen	10	40	.X.		

*1=easily diggable, 2=diggable with limitations, 3=nondiggable.

TABLE 2: SUMMARY OF ROCK CUTTING TEST RESULTS
FOR MINES IN ALBERTA AND SASKATCHEWAN
(Continued)

SAMPLE NUMBER	ROCK TYPE	CONDITION Temp. C°	CUTTING RESISTANCE (N/cm ²)		DIGGABILITY RATING*		
			First Cut	Strongest Cut	1	2	3
Highvale No. 1	Sandstone	Frozen -24°	142	372	.	.X.	
Highvale No. 2a	Sandstone; cal- careous cement	Frozen -24°	327	528	.	. .X.	
Highvale No. 2b	Sandstone; cal- careous cement	Frozen - 6°	228	287	.	. .X.	
Highvale No. 4a	Siltstone; cal- careous cement	Frozen -24°	708	708	.	. .X.	
Highvale No. 4b	Siltstone; cal- careous cement	Frozen - 6°	172	562	.	.X.	
Highvale No. 5	Siltstone; cal- careous cement	Frozen -24°	329	1117	.	. .X.	
Whitewood No. 6	Silt Till	Frozen -24°	115	295	.	.X.	
Whitewood No. 7	Silt Till	Frozen -24°	133	250	.	.X.	
Whitewood No. 8	Silt Till	Frozen -24°	108	366	.	.X.	
Diplomat No. 9	Silt Till	Frozen -24°	101	184	.	.X.	
Diplomat No. 10	Silt Till	Frozen -24°	122	428			

*1=easily diggable, 2=diggable with limitations, 3=nondiggable.

TABLE 3: SUMMARY OF MATERIAL STRENGTH IN RHEINBRAUN'S MINES

DATE	MINE	BENCH	OVERBURDEN MATERIAL	STRATA	NO. OF SAMPLES	TYPE OF TEST	N/cm ²			DIGGABILITY*		
							AVERAGE	MINIMUM	MAXIMUM	1	2	3
06/01/77	Fortuna	2	Int. Sand & Clay	9	2	2	109.9	108.9	109.9	.X.		
09/23/75	Fortuna	1	Clay		4	K1	25.7	13.9	38.7	.X.		
		1	Sandstone		16	K1	991.1	429.8	1,909.0	. .	. .	.X.
					(7)		(856.8)	(509.7)	(1,539.2)	. .	. .	.X.
		2	Red Clay		6	K1	182.4	49.9	309.8	. .	.X.	
					(5)		(273.9)	(130.0)	(259.9)	. .	.X.	
		3	Red Clay		5	K1	101.7	85.0	115.5	. .	.X.	
		6	Coal		2	K1	388.7	-	-	.X.		
					(3)		(357.3)	-	-	.X.		
		6	Coal		4	K1	382.7	-	-	.X.		
					(2)		(371.6)	-	-	.X.		
04/12/77	Fortuna	2	Clay	13	5	2	13.1	11.4	14.0	.X.		
		2	Clay	13	3	2	15.2	10.9	17.9	.X.		
		6	Coal	6	6	2	186.4	169.8	196.0	.X.		
12/14/78	Fortuna	2	Sandstone		6	K1	3,520.0	2,710.0	4,980.0	. .	. .	.X.
			Sandstone		5	K1	3,510.0	2,330.0	4,720.0	. .	. .	.X.
01/23/79	Frechen	4	Claystone	7	7	2	5,664.3	2,688.3	9,452.1	. .	. .	.X.
02/12/78	Frechen	4	Clay	7	4	2	124.3	116.3	143.8	. .	.X.	

TABLE 3: SUMMARY OF MATERIAL STRENGTH IN RHEINBRAUN'S MINES
Continued

DATE	MINE	BENCH	OVERBURDEN MATERIAL	STRATA	NO. OF SAMPLES	TYPE OF TEST	N/cm ²			DIGGABILITY*		
							AVERAGE	MINIMUM	MAXIMUM	1	2	3
02/12/79	Frechen	4	Clay	7	5	2	144.7	129.1	174.4	.	.	.X.
	Frechen	4	Clay	7	2	2	40.5	29.1	52.0	.	.	.X.
	Fortuna	3	Clay	7	11	2	43.1	26.5	67.2	.X.		
08/13/80	Fortuna	7	Coal	6	15	2	437.4	245.3	749.5	.	.	.X.
08/30/79	Fortuna	5	Coal	6	6	2	407.0	266.2	473.6	.	.	.X.
10/23/79	Fortuna	4	Int. Sand & Clay	7	8	2	89.9	71.6	96.3	.X.		
04/24/80	Zukunft	5	Int. Sand & Clay	6B	5	2	63.9	61.2	66.9	.	.	.X.
			Int. Sand & Clay	6B	4	2	143.3	115.2	167.4	.	.	.X.
			Int. Sand & Clay	6B	5	2	63.0	38.8	96.5	.	.	.X.
04/12/80	Fortuna	6	Coal	6AE	24	2	366.3	75.4	604.3	.	.	.X.
02/12/81	Fortuna	7	Coal	6AC	32	2	405.9	131.3	596.6	.	.	.X.
01/12/81	Fortuna	7	Woody Coal	6AC	1	2	251.7		insufficient quantity	.	.	.X.

*1=easily diggable, 2=diggable with limitations, 3=nondiggable.

TABLE 4: SUMMARY OF MATERIAL STRENGTH IN MINES WORLDWIDE

DATE	MINE	BENCH	OVERBURDEN MATERIAL	STRATA	NO. OF SAMPLES	TYPE OF TEST	N/cm ²			DIGGABILITY*		
							AVERAGE	MINIMUM	MAXIMUM	1	2	3
03/25/77	Winfield Texas		Siltstone		4	2	193.3	183.4	218.8	.X.		
09/05/77	Sao Matheo		Oilshale		5	1.2	1,373.4	-	-	Rating impossible		
07/12/77	Tolsa Spain		Sepiolith		1	1	436.5	-	-	.X.		
03/31/78	Turlington Texas		Sandstone		7	2	1,132.8	475.2	872.9	. .		.X.
		Sandstone		2	2	334.5	334.5	-	. .		.X.	
04/22/80	BukitAsam Indonesia		Claystone		3	OK	107.1	94.4	119.0	. .		.X.
				3	KJ	1,116.7	800.0	1,300.0	. .		. .	.X.
				4	2	586.0	428.5	733.6	. .		.X.	
09/02/80	Kingston Australia		Limestone		2	Shear	234.7	203.2	266.1			
				3	2	912.2	647.8	1,096.9	. .		. .	.X.
				3	OK2	323.2	205.7	242.2	. .		.X.	
				9	2	138.4	89.7	164.7	.X.			
			Limestone (Altered)		8	OK2	92.0	18.6	65.8	.X.		
			Limestone		2	2	295.5	261.5	329.4	. .		.X.
			Limestone		3	OK2	39.2	36.8	41.1	.X.		
				3	2	766.0	98.2	1,471.7	. .		. .	.X.
				5	OK2	160.7	26.8	345.3	.X.			

44.

*1=easily diggable, 2=diggable with limitations, 3=nondiggable.

Australia. The assessment of whether the tougher materials are cuttable with a BWE is a combination of objective and subjective evaluation by experienced engineers.

The data presented in Tables 2, 3 and 4 have been obtained from the following tests:

- ° O&K wedge test with slenderness ratio of 1 OK1
- ° Krupp unconfined compressive test with slenderness ratio of 1 K1
- ° Unconfined compressive test DIN 18 136, with slenderness ratio of 2 2
- ° O&K wedge test with slenderness ratio of 2 OK2
- ° Unconfined compression tests with various slenderness ratios ratios given

Although many objective test procedures are in use, the science of correlating these results with an acceptable degree of reliability with actual BWE performance is still in its infancy. Cross correlation between various types of tests is normally not possible. Whenever such correlations were done, they were based on limited number of data points. Nonetheless, comments regarding likely trends in cross correlation of several of the more popular types of tests are warranted.

Recently sample material was obtained from the proposed Bukit Asam mine in Indonesia which was tested by both Rheinbraun laboratories and also by the equipment manufacturers O&K and by Krupp. The tests were conducted on a 12 m section of core distributed to each of the three laboratories.

The core was divided as follows:

Sample No. 1	118.42 to 118.63 m to RC
Sample No. 2	123.85 to 124.02 m to O&K
Sample No. 3	126.90 to 127.13 m to RC
Sample No. 4	128.56 to 128.80 m to Krupp
Sample No. 5	130.83 to 131.05 m to RC

The core samples were grey-brown stratified sandstones with a 90 quartz content with irregular brown iron hydroxide inclusions.

The results of the tests are summarized in Table 4. These results show that the Krupp unconfined compression test shows a breaking strength which is 10 times as high as that recorded by the O&K cutting test. The breaking force recorded in the unconfined compression test by Rheinbraun is 5 times that recorded by the O&K test. To what extent these results are applicable for comparison of these three test methods for other materials is not known. It is likely that this relationship may only hold for tougher and somewhat brittler materials. The above correlation may be expressed as:

$$\text{Krupp} = 2\text{RBW} = 10 \text{ O\&K}$$

Another interesting project from which some indication of correlation can be seen is one performed on a limestone formation obtained from a property in Australia. From Table 5 it can be seen that 36 individual tests were made. Seventeen of the tests were unconfined compression tests performed in accordance with DIN 18 136 (equivalent to ASTM D 2938-79), and nineteen tests according to O&K procedures but with a

TABLE 5: COMPARISON OF O&K, KRUPP AND RHEINBRAUN TEST RESULTS

LABORATORY	TYPE OF TEST	SAMPLE SIZE	SLENDerness RATIO	FORCE (N/CM ²)
O&K LUBECK	Wedge	6.0 X 6.0	1.00	119.0
		6.0 X 6.5	1.08	108.0
			0.58	<u>94.4</u>
				Average 107.1
KRUPP DUISBERG	Unconfined Compressive	6.0 X 5	0.83	1250.0
		6.0 X 5	0.83	1300.0
		6.0 X 5	0.83	<u>800.0</u>
				Average 116.7
RHEINBRAUN COLOGNE	DIN18 136	6.05 X 12.01	1.99	549.3
		6.05 X 7.93	1.31	733.6
		6.00 X 10.43	1.74	631.5
		6.02 X 10.05	1.67	<u>428.5</u>
				Average 585.7

larger slenderness ratio of 2 rather than 1. Since these tests were performed on groups of similar samples the average of each group was determined.

These results are shown on a graph where the averages of the unconfined compression strength test averages are plotted against the averages of the O&K cutting test. The results of the already mentioned Bukit Asam tests are also plotted on this graph. The curve produced on Figure 9 indicates that the correlation factor is not a constant but may be a non-linear function with unknown dispersion. Generally speaking the observation is consistent with trends expected from these two types of tests. The uppermost values approach the strength of the sandstones in the Neyvelli Mine in India where blasting is often required.

After the material strength, formation thickness, joint spacing and fracturing (natural and/or after blasting) are the next important elements affecting the bucket wheel excavator operation. Some examples where the bucket wheel excavator is used successfully are: in the Neyville Mine, hard rock with a strength of 320 N/cm^2 (wedge test equivalent value) and 200mm in thickness is mined with a bucket wheel excavator. In the Ptolemais Mine, Greece, rock strengths up to 1600 N/cm^2 in formations less than 100 mm thick were reported to be mined without undue difficulty. Reports indicate that in the Ekibastusz Mine, U.S.S.R., formations with a strength of 480 N/cm^2 and thickness up to 1 m are mined after blasting (3)*.

In this report it has been previously stated that strength values alone cannot be used to determine cutting resistance

* See References.

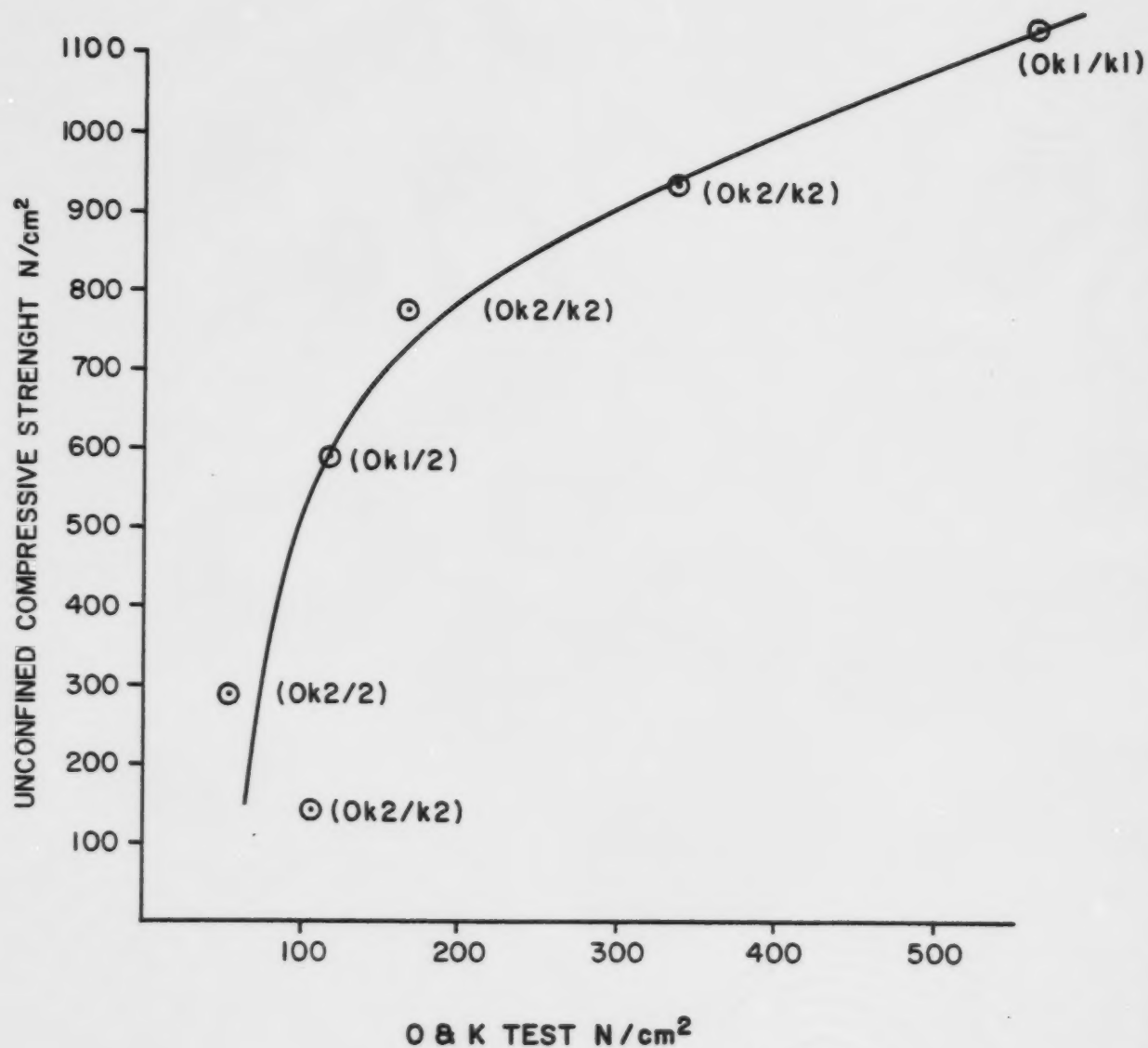
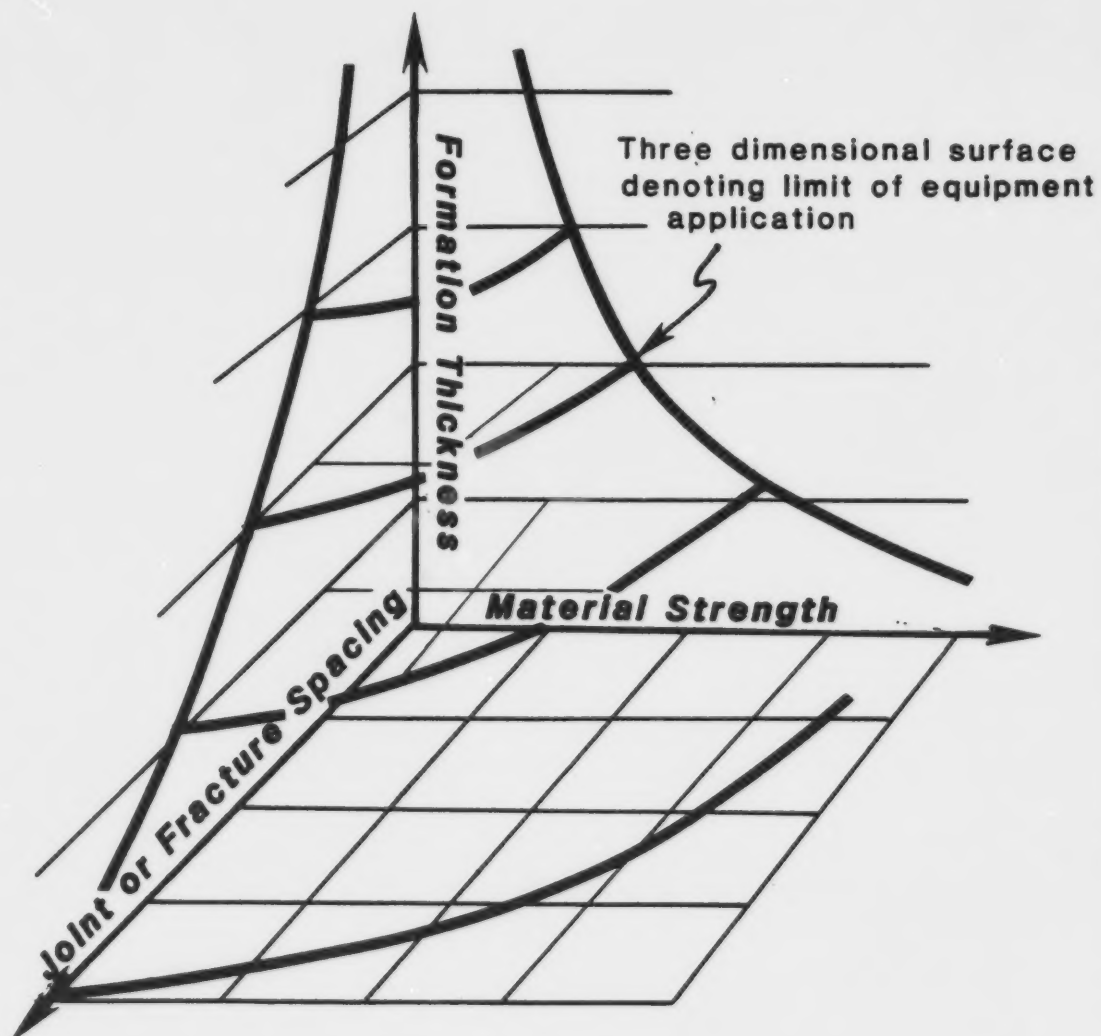


FIGURE 9 RELATIONSHIP BETWEEN UNCONFINED COMPRESSIVE STRENGTH AND CUTTING RESISTANCE (SANDSTONE & LIMESTONE)

and ultimate digability. A good rating would quantify formation thickness and joint spacing along with material strength. This would, of course, be complemented with geological evaluation and understanding of the material being tested.

It is believed that with sufficient data the applicability of bucket wheel excavator could be expressed by performance surfaces or envelopes separating mine sites with easily cuttable materials from those having totally uncuttable materials. Such surfaces could be drawn for various bucket wheel excavators as well as other equipment like draglines, shovels, and front-end loaders. In this way, zones of application, some of which would be overlapping, could be designated graphically. The concept is illustrated schematically in Figure 10 for one particular type of excavator.



Data points plotting above the surface would indicate a field condition where the equipment should not be applied. In reality such a surface would have a thickness indicating a zone of marginal application.

FIGURE 10 THREE DIMENSIONAL CUTTABILITY PLOT

9.0 FACTORS DETERMINING THE APPLICABILITY OF BUCKET WHEEL EXCAVATORS

During the first half of the twentieth century bucket wheel excavators (BWE) found worldwide application in unconsolidated and weakly consolidated overburden. In recent years, BWE's with greater digging power have been designed and commissioned for the excavation of more solidified materials, even sandstones. In latter cases, supportive blasting is sometimes carried out to fracture the material and facilitate excavation.

The designers of all types of excavating equipment expect that operators will apply their machines in such a manner that the highest possible production is achieved. This means that both the cutting aspect as well as the loading aspects are optimized. Both are critical to the economic operation of any excavating machine be it a BWE, a dragline, a shovel or a front-end loader.

When material is excavated, the cutting edge must first sever an amount of material from the main mass. To do this a cutting force is applied. If the material is indurated (e.g. siltstone) this force will be used to fracture the materials. If the material is a dense or hard soil (e.g. till), a force will be applied to loosen the material to be loaded. In the event that the material is loose (e.g. gravel, disturbed till, or fractured rock) a force still will be necessary to allow the bucket to penetrate the mass. In cohesive soils, a large force may also be required. During a loading cycle this force will usually build up and then rapidly fall off once separation of the material has occurred.

Excavating tools are normally designed to utilize the maximum force of gravity in the loading cycle. Ideally, once the material has been separated from the main mass, it will fall into the loading container under gravity. Unfortunately, this seldom happens. The flow of material into the chute is often thwarted by one or a combination of: bridging of the material, sliding resistance, cohesion or even overfilling.

The objective of this report is to examine the breaking or separation component of the loading cycle for various materials found in the plains coal mines of Alberta and Saskatchewan. Under most conditions the cutting resistance of the rock strata determines whether a BWE can be used. In many mines an experienced engineer can establish the applicability of a BWE. In marginal situations quantitative information has to be obtained to evaluate the applicability of a bucket wheel excavator.

Some of the major factors influencing cutting resistance are:

- ° strength of in situ material to be cut (obtained from compression and/or shear tests)
- ° cohesiveness of disturbed material
- ° nature of geologic deposition and stratification (frequency of occurrence bedding, cementation, grain size, etc.)
- ° degree of jointing
- ° presence of hard inclusions
- ° massiveness of formation (structure thickness, areal extent)

- ° temperature (freezing and frost penetration)
- ° groundwater conditions

The above factors must be evaluated as a whole by experienced engineers.

In any given situation many of the components will interact. Strong material may be easily cut if it is highly jointed or if it occurs in thin layers of less than 30 cm thickness. In contrast, a weak but highly plastic clay may greatly reduce a bucket wheel excavator's output.

BWE designers and mine planners have a number of methods to excavate "marginal" material. Some of these may include:

- ° increasing the driving power of the bucket wheel
- ° shaping the cutting edge of the bucket lip or the bucket teeth to concentrate the digging force
- ° varying slewing speed, cutting height and slice thickness
- ° develop a mine plan (bench orientation) to take advantage of weaknesses along joints or depositional layering.

The first two methods are incorporated in the design of the bucket wheel excavator and thus have to be known before the machine is selected or constructed. Consequently, the greatest effort is placed into evaluating the cutting resistance of the highwall material. Once the cutting resistance is established, the mine planner with the bucket wheel designer decide whether a bucket wheel excavator:

- ° is not applicable
- ° can be used with reduced capacity with blasting
- ° can be used with reduced capacity without blasting
- ° can be used without any capacity loss.

The last three methods are optimized most effectively in the mine during BWE operation.

Many test methods have been devised and used to evaluate the cutting resistance of rocks. As yet, no common or standardized method(s) have been adopted by researchers, equipment manufacturers or mine operators. Nevertheless, values for cutting resistance are frequently stated as either:

- ° force applied per one centimeter of the cutting edge of a bucket tooth or bucket lip (N/cm)
- ° force applied to the cross-section of the slice that is cut by the bucket tooth or lip (N/cm²)

In this report most test results referred to are stated in N/cm².

A precise classification or rating of cutability based on one test alone is not very reliable. Nonetheless, based on the experience of Rheinbraun staff with O&K type tests, a generalized classification is as follows:

<u>N/cm²</u>	<u>Digability Rating</u>
0 to 100	digable without loss in capacity
100 to 150	digable with certain loss in capacity
150 to 240	digable, but blasting required and loss in capacity is likely
240 plus	generally not digable except when extremely jointed or fractured and loss in capacity is unavoidable

This type of rating is valid only if all major influencing factors are combined and judged at the same time. The application of the above scale should never exclude a broader and experienced professional assessment of the specific situation at hand.

10.0 GENERAL FINDINGS

Bucket wheel excavators can be applied to all plains coal mines in Alberta and Saskatchewan. The bulk of overburden in all plains coal mines is amenable to efficient removal with a bucket wheel excavator. Several mines have tougher layers which may require removal with auxiliary equipment. As experience is gained in excavating all of or at least part of this tougher formation with a BWE, the size of the auxiliary equipment fleet will be eliminated. In existing mines the application of a BWE will be decided primarily on the need to supply additional stripping capacities as the draglines encounter overburden depths beyond their practical operating limit. In new mines, serious consideration should be given to the bucket wheel excavator as the primary overburden stripping machine. Selective mining and placement of overburden is facilitated by the application of a bucket wheel mining system.

The geologic conditions prevailing in plains coal mines do not pose a limitation with respect to the application of BWE's. For existing mines the application is limited, however, by the prevailing economic situation at each mine. Existing mines have already made a large capital investment in their primary stripping equipment. A large expenditure on another primary stripping unit cannot be justified until the mines are either expanded or reach overburden depths substantially beyond the practical operating limits of existing draglines and until the additional stripping capacity makes the use of auxiliary overburden equipment more expensive than the cost of purchasing and operating of a primary bucket wheel stripping system.

Several of the mines do contain formations which cannot be excavated with a BWE or can be excavated with considerable loss in production capacity without prior blasting. The sandstone observed in the Highvale mine is such an example. Whenever such a formation is located above the coal such a formation can be blasted and then removed by the BWE or auxiliary machinery.

The production of a bucket wheel mining system will be greatly reduced when excavating frozen overburden. The effect of freezing can, however, be minimized by selecting a mine layout which eliminates the long narrow pit typical in the traditional dragline mine. A block layout which reduces the length of the active mining face will reduce frost penetration.

Prior to the selection of a suitable design for a BWE for a mine, the material of the formations must be tested. The testing will provide data which can be used by the BWE designer to estimate the cutting forces exerted by the teeth of the bucket wheel. The dimensions of the boom and the overall weight of the excavator will be primarily determined as a result of the estimated maximum digging forces. Knowledge of the areal extent and volume of the formation will affect the production capacity of the wheel. This will, in turn, also affect the size and weight of the BWE. Both the strength and the relative dispersion of materials must be known to properly size and design a BWE.

To date, a common test to determine the applicability of a bucket wheel excavator does not exist. Manufacturers appear to have individual preferences based on a combination of

their approach to the design of BWE and the type of test data collected and used in the past.

A universal acceptable test procedure is unlikely to be chosen by the BWE manufacturers and mine operators in the near future. Consequently the industry will continue to develop a variety of test data and the need for research in methods for cross correlating data is increasing as interest in BWE's grows. At this time, however, it appears that any series of tests selected should be accompanied by uniaxial compressive tests performed on similar material.

In addition to the primary testing process and identification of the material to be tested, it is necessary to make an accurate assessment of the following field conditions:

- ° relative distribution of materials of different strength
- ° massiveness of individual formations
- ° degree and orientation of jointing and fracturing in the hard formations
- ° degree of water saturation in plastic formations after pit wall drainage
- ° cohesiveness of the materials to be excavated
- ° extent of frost penetration on active working faces in the mine.

No single factor should be allowed to influence the mine planners and equipment designers during the selection of a mining method or excavating machinery. Optimum mine layout and machine design will be a compromise which will allow the mine operator to achieve the lowest overall mining costs.

11.0 RANKING OF PLAINS COAL MINES FOR THE APPLICATION OF BUCKET WHEEL EXCAVATORS

In coal mines where operators have developed extensive experience with traditional combination of mining equipment, the introduction of a 'new' mining equipment may be viewed with reluctance. The reason is that the performance is difficult to predict in the new environment. Since profit margins in coal mines are often small, the operators are reluctant to take risks in applying new mining technology. Due to the lack of hands-on-experience and realistic risk assessment, the introduction of a rather effective alternative mine equipment may be avoided indefinitely.

It is suggested that among all the plains coal strip mines in Alberta and Saskatchewan, research into bucket wheel excavator applications would benefit most from the introduction of a BWE in the Whitewood Mine. This mine has a wide variety of geological conditions which would allow the excavator to be extensively tested, so a bucket wheel excavator could be incorporated into the mine's equipment fleet with considerable economic advantage.

The following operational capability of the bucket wheel excavator could be demonstrated in the Whitewood Mine:

- a. Flexibility of the bucket wheel to excavate materials with various strengths and handling characteristics.

The bucket wheel excavator would work in a wide variety of materials ranging from gravels to consolidated clays. In some areas of the Whitewood Mine hard and sandy clay prevail

which would require a bucket wheel equipped with a high torque. The difficulties of handling saturated, dry, granular, cohesive and blocky material with a single excavator can be demonstrated. A variety of bucket and teeth designs would be tested.

b. Capability to mine selectively.

The capability to excavate multiple products in one bench would also be demonstrated. In addition to multiseam coal production, gravel is separated on the site for commercial use.

c. The ability to operate in pitching and rolling formations.

The undulation of the coal seams and other strata make it desirable to vary elevation of working benches. A bucket wheel can follow the undulations or selectively mine as its bench passes through the undulations. The ability to separate different materials coming from a single mining face will be shown.

d. Capability to operate efficiently from multiple benches.

A bucket wheel excavator can load a belt conveyor from a number of different positions on the pit wall. Thus the sequence in which material is excavated can be selected with considerable flexibility. The excavator can remove a given material for a period of time from the uppermost part of the highwall, then move to another bench and mine materials low in stratigraphic position in the highwall. The excavator can

also be adapted to reach below crawler grade to remove material to a specific stratigraphic boundary.

e. Capability to work on soft ground.

The crawler design and the low ground pressure of the bucket wheel excavator permit the machine to work on soft ground on which draglines, shovels and trucks would encounter difficulties. A bucket wheel excavator requires only a minimal amount of bench preparation prior to traversing to the next operating position.

The above reasons indicate that the Whitewood Mine would be a very appropriate demonstration site.

The Highvale Mine would rank second as a demonstration site since the materials which can be mined using a bucket wheel excavator are rather uniform and the hard sandstone formation will require a secondary mining system. As the stripping ratios in this mine are increased a bucket wheel may be an appropriately overburden stripping machine.

The Vesta, Forestburg South (Paintearth), Roselyn (Shear-ness), Poplar River, Souris Valley Mines are good candidates for bucket wheel excavators because these mines could reach depths approaching or exceeding the practical operating limits of available draglines. Furthermore selective back-filling of overburden may improve reclamation practices.

The depths to which the above plains coal mines are likely to operate in the near future would allow the application of BWE loaded cross-pit conveyors in conjunction with the application of draglines. In a conventional BWE mine, conveyors transport excavated material around the pit to spreaders which dump the material. Overall, a comparatively larger capital investment may be required if the mining depth is within the operational range of suitably designed cross-pit conveyors. Research conducted thus far indicates that there could be a marked improvement in the operation of coal strip mines with respect to selective placement of overburden, subsoil and topsoil by combining the use of draglines, bucket wheel excavators and cross-pit conveyors, (4).

12.0 RECOMMENDATIONS FOR RESEARCH

Further investigations with respect to the application of bucket wheel excavators in plain coal strip mines could proceed in several directions. Some potential projects are:

- PROJECT 1. Test Methods Evaluation and Correlation to Bucket Wheel Performance.
- PROJECT 2. Field Evaluation of Bucket Wheel Excavators for Canadian Plains Coal Mines.
- PROJECT 3. Field Testing and Instrumentation of existing Bucket Wheel-Excavator in Similar Conditions.
- PROJECT 4. Develop Application Ratings for Bucket Wheel Excavators, Draglines, Shovels and Front-End Loaders.
- PROJECT 5. Quantify Geological Conditions in Plains Coal Mines.

- PROJECT 1. Test Methods Evaluation and Correlation to Bucket Wheel Performance.

Evaluation of existing test methods to select and recommend the most meaningful and practical method(s), develop a correlation between commonly used methods and develop cross cor-

relation between test methods and BWE performance from available published data.

A large number of test methods are available which are used to evaluate the cutability of excavators. The results are used by different mine operators to correlate the performance of excavators and develop empirical correlations between test results and the performance of equipment.

The proposed project should consists of three parts, namely:

- * Review all test methods which have been used in the past to measure strength of geological formation and cutting resistance. The review should consider the theoretical test and stress conditions, practical aspects of the method so their use could become widely known. Based on this one or more type of tests would be recommended.

- * Using the recommended and most frequently used method conduct a program on selected representative materials to develop a correlation between the results of the different test methods.

- * Review all existing published correlations between the individual test methods and BWE performance to develop basic correlations between strength and BWE performance.

PROJECT 2. Field Evaluation of Bucket Wheel Excavators for Canadian Plains Coal Mines.

Evaluate the performance of BWE for potential Canadian conditions by studying the performance of production BWE in existing mines internationally operating in similar strata.

For this project the existing mines using BWE would be reviewed and mines with similar material strata identified.

The goal of this project would be to carefully monitor excavator performance in similar formations and to extrapolate the performances to Canadian conditions. The project would begin by testing soil and rock samples in candidate mines. Once comparable strata have been defined, an appropriate performance test of the bucket wheel excavator(s) in that mine would be conducted. Engineers would use this data to more accurately assess the applicability of bucket wheel excavators under conditions found in Canadian Plains Coal Mines.

PROJECT 3. Field Testing and Instrumentation of Bucket Wheel Excavator in Canadian Plains Coal Mines.

Ideally based on the previous two projects a demonstration project where a BWE would be instrumented and field tested for a representative Canadian Plains Coal Mine.

A large scale demonstration of a bucket wheel excavator would require mine planning and engineering at the outset. As well, an equipment selection process and certain elements of

equipment design or redesign would be required to meet conditions existing at the proposed demonstration site and finally lead to bonafide operation in a mine. In order to obtain a reliable appraisal, the test equipment must be operated through several complete cycles of seasons. Field observations and monitoring activities would continue over the life of the test period. The final product would be a fair and realistic appraisal of the equipment's and the mining method's performance reported by experienced engineers and mine managers. The primary beneficiaries of this demonstration would be mine operators and utilities contemplating the expansion or the opening of new mines. A lesser benefit but a truly recoverable one, would occur to the participants as a result of the generation of a marketable technology or experience package.

The expense could be entirely borne by CANMET or shared with others. For example, the expense could be partly borne by a manufacturer as a promotion. Several mining organizations may choose to subsidize the demonstration expenses provided that there is a real opportunity to reduce mining costs in the future as a result of the findings and experience gained by this type of testing. A combination of the above supporters could provide the necessary financial support needed for a particular mine to induce it to commission and test a certain set of machinery or mining methods.

PROJECT 4. Develop Applications Ratings for Bucket Wheel Excavators, Draglines, Shovels and Front-End-Loaders.

Once testing methods and interpretation techniques have been sufficiently developed, and sufficient data has been obtained from field sampling programs, an equipment applicability evaluation technique should be developed. This project would attempt to define the optimal geological field conditions for bucket wheel excavators, draglines, shovels, loaders, etc. Application envelopes similar to that shown in Figure 10 would be developed for each type of machinery in terms of the formation thickness, the joint or fracture spacing and the material strength. The results of this project would be beneficial to mine planning engineers and mine developers concerned with optimizing equipment selection and minimizing the cost of coal to utilities. This project would likely have costs similar to the first item but likely much lower costs than the second project.

PROJECT 5. Quantify Geological Conditions in Plains Coal Mines

The emphasis in this project would be to classify materials to be excavated and to conduct an inventory of geological formations present in plains coal fields. The program would begin by testing numerous samples taken from fresh mining faces. The amount of drilling and core sampling would depend on the size of the coal field under investigation and its likelihood of development in the near future. Samples would be tested using a test procedures identified in Project 1 as the most relevant. The test procedures may vary with the

types of material being tested. In addition, all sample groups would be subject to at least one standard test in order to provide a means of correlation and a kind of continuity over the entire range of materials being tested. The primary beneficiary of this work would be coal mining and oil sands mining organizations contemplating the opening of new mines or the expansion of existing mines.

APPENDIX I

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APPENDIX II

LITHOLOGICAL DESCRIPTIONS

LITHOLOGIC DESCRIPTIONS

Highvale Sample No. 1

Siltstone; slightly sandy (very fine grained); thin bedded; structureless; calcareous cement; well sorted; medium grey.

RH-3 medium hard

Highvale Sample No. 2

Claystone; thin bedded; beds unequal thicknesss, continuous and laterally uniform thickness; a 5 cm thick interbed of bentonic (hard) rich claystone; contacts are convoluted, sharp and conformable; carbonaceous partings; fractures iron stained; calcareous cement; medium to dark grey; bentonite creamy grey.

RH-1 to RH-2 medium soft

Highvale Sample No. 3

Similar to Highvale No. 1.

Highvale Sample No. 4

Sandstone; fine to medium grained; "salt and pepper" appearance; thin bedded; structureless; friable; moderately well sorted; subangular to subround; grey.

RH-1 soft

Highvale Sample No. 5

Siltstone; sandy; very fine and fine grained; thin bedded; discontinuous laterally variable laminae of carbonaceous rich claystone; laminae of iron cemented sandstone; calcareous cement; moderate to poor sorting; medium grey.

RH-3 medium hard

Highvale Sample No. 6

Siltstone; sandy; very fine and fine grained; thin bedded; thin discontinuous sub horizontal laminae of claystone; light grey.

RH-1 to RH-2 medium soft.

Diplomat Sample No. 1

Silt Till; sandy; gravel to 1.5 cm diameter; coal fragments; dense; dark brown, RH-1 soft

Diplomat Sample No. 2

Similar to sample no. 1; iron stained joints.

Souris Valley Sample No. 1

Claystone; silty; thin bedded; structureless; carbonaceous partings; plant fragments; brittle; calcareous cement; yellow brown; marl-like.

RH-2 medium soft

Souris Valley Sample No. 2

Claystone; thin bedded; structureless; calcareous cement; medium grey.

RH-e medium hard

Souris Valley Sample No. 3

Similar to sample No. 2.

Souris Valley Sample No. 4

Similar to sample No. 2.

Poplar River Sample No. 1

Siltstone; clayey; thin bedded; structureless; carbonaceous fragments; calcareous cement; light grey.

RH-2 to RH-3 medium hard

Poplar River Sample No. 2

Similar to sample No. 1.

Poplar River Sample No. 3

Similar to sample No. 1.

Highvale Frozen Sample No. 1

Sandstone; fine to medium grained; structureless; poorly indurated; moderately well sorted; subangular to subround; light brown grey

RH-2 medium soft

Highvale Frozen Sample No. 2a

Sandstone; fine to medium grained; "salt and pepper" appearance;
structureless; moderately well sorted; subangular to sub-
round; calcareous cement; medium grey
RH-3 medium hard

Highvale Frozen Sample No. 2b

Similar to Highvale frozen No. 2

Highvale Frozen Sample No. 3

Similar to Highvale frozen No. 2 except poorly indurated
RH-1 soft

Highvale Frozen Sample No. 4a

Siltstone; thin bedded; beds continuous, horizontal and lateral-
ly variable; carbonaceous partings; calcareous cement; car-
bonaceous debris
RH-3 medium hard

Highvale Frozen Sample No. 4b

Similar to Highvale frozen No. 4a

Highvale Frozen Sample No. 5

Similar to Highvale frozen No. 4a

Whitewood Frozen Sample No. 6

Silt Till; gravel to 1 cm diameter; coal fragments; dense;
medium brown
RH-1 soft

Whitewood Frozen Sample No. 7

Similar to Whitewood frozen No. 6

Whitewood Frozen Sample No. 8

Similar to Whitewood frozen No. 6

Diplomat Frozen Sample No. 9

Silt Till; gravel to 1.5 cm diameter; coal fragments; dense;
medium yellow brown
RH-1 soft

Diplomat Frozen Sample No. 10

Similar to Diplomat frozen No. 9

SCALE OF ROCK HARDNESS

After Panama Canal Company (1959)

RH-1	<u>Soft</u>	Slightly harder than very hard overburden, rock-like character but crumbles or breaks easily by hand. (Some clay-shales and uncemented sandstones and agglomerates).
RH-2	<u>Medium Soft</u>	Cannot be crumbled between fingers, but can be easily picked with light blows of the geology hammer. (Some shales and slightly-cemented sandstones and agglomerates).
RH-3	<u>Medium Hard</u>	Can be picked with moderate blows of geology hammer. Can be cut with knife.
RH-4	<u>Hard</u>	Cannot be picked with geology hammer, but can be chipped with moderate blows of the hammer.
RH-5	<u>Very Hard</u>	Chips can be broken off only with heavy blows of the geology hammer.

APPENDIX III

O&K TEST SPECIFICATIONS

00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99

- ### C Testing the soil samples

[illegible]

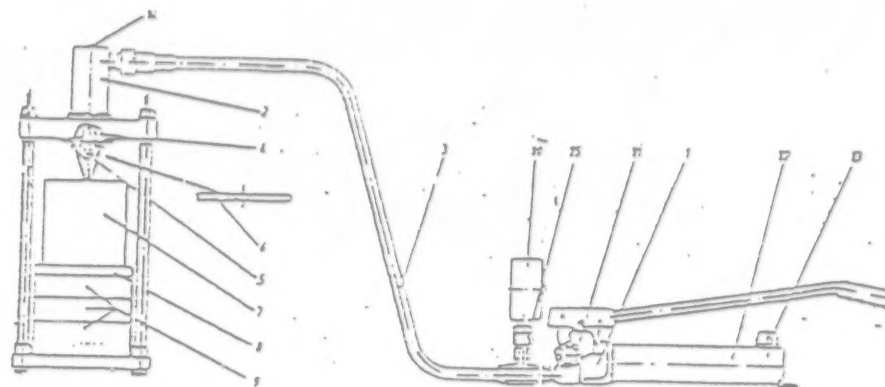
A Description of the Equipment

1. Application

The equipment shown was developed to obtain soil characteristics with regard to strength. In view of its high speed of operation and simple operation it is especially suited for use on sites. Its application allows the following characteristics to be determined:

- 1) Specific cutting force (division of the sample by means of test wedges)
- 2) Compression resistance in one axis only (destruction of the sample between two plate-parallel plates).

2. Schematic Arrangement



- 1 hand pump
- 2 cylinder
- 3 connecting line
- 4 piston
- 5 test wedge
- 6 test plate
- 7 soil sample

- 8 sand box
- 9 blocks
- 10 pressure gauge
- 11 shut-off valve
- 12 storage tank
- 13 closing cover
- 14 venting screw
- 15 spigot nut

Grenstein & Koppel		Sach-Nr. Ref. No.	
Aktiengesellschaft		834 601	
Ingenieur- und Bauingenieur-Verlag		1934	
1934		1934	

Design and Principles

The main part of the instrument is a hydraulic press. By operating hand pump (1) pressure oil is admitted to the cylinder (2) via connecting line (3). The pressure exerted on the piston (4) can either be transmitted by a test wedge (5) (determination of the specific cutting forces) or a square plate (6) (determination of the compression resistance in one axis) into the test piece (7).

To ensure that the sample is evenly supported, it is necessary to embed the soil sample in a box (8) filled with sand.

As the effective stroke length of the piston is limited, blocks (9) are provided as compensation in height when testing smaller samples.

The load on the sample is increased until it breaks. The maximum pressure reached at the instant of cutting the sample is indicated on a pressure gauge (10) with maximum pointer. A total of three pressure gauges with varying pressure ranges are provided. Their application depends on the hardness of the test material to be examined.

4. Instructions for Operation

4.1 Operation of Hand Pump

When using the hand pump, valve (11) has to be closed by turning the hand wheel to the right. By opening the valve, the piston is relieved.

To ensure pressure compensation in the storage tank (12), screw plug (13) must be open during operation. This screw plug has to be closed for transport.

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				Aktiengesellschaft		834 607		Sheet
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Working oil circulation can be replaced during the filling hole in the cylinder block. For protection a plug is put into the hole.

4.2 Venting of the system

To prevent air from entering into the system and in order to keep leakage oil losses as low as possible, pump and cylinder should not be disconnected. At venting of the system which will be necessary, the procedure is as follows:

- 1) Opening of the venting screw (14) at the top side of the cylinder
- 2) Slow operation of the pump until oil comes out of the opening
- 3) Closing the screw plug (14)

4.3 Removal of the test valve and the test plate

The test valve can be screwed to the underside of the piston. When dismantling the exposed thread is to be protected from dirt.

Between test plate and piston there is no positive connection. The plate is provided with a pocket bore which is provided to accommodate the underside of the piston.

4.4 Changing over of Pressure Gauge

The pressure gauge is fastened to the system by a spigot nut (15), so that it can be taken off.

It must be ensured in any case that prior to beginning a new test series the pressure gauge with the maximum range is inserted. If during the test it should be found that the working range is too great and, therefore, the measured values are not indicated with adequate

			Orenstein & Koppel		Sach-Nr.	
Aktiengesellschaft					L Stoff 4	
mtl. Ant.-Nr. Dator. Name Urspr.			Vers. Nr.		Vers. durch	
					F.V. G. B. H.	

precision, the pressure gauge is to be replaced by
the next smaller size.

Note: If the pressure gauge used is too small,
it will be destroyed by overload!

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		Aktiengesellschaft				F K		7.9.1911	
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II. Taking Soil Samples

1. Selection of Soil Samples

- 1.1 Test samples for various drilled cores
- 1.2 Test cubes for various places in the open cast

2. Dimensions of Soil Samples

2.1 Soil samples to determine the specific cutting forces

2.1.1 Core samples: diameter = drilling core diameter
height = drilling core diameter

2.1.2 Test cubes: 15 cm x 15 cm x 15 cm

2.2 Soil samples to determine the compression resistance

2.2.1 Core samples: diameter = drilling core diameter
height = 2 x drilling core diameter

In case of very hard test material,
test cubes are to be cut from the
drilling cores to the dimension
indicated in item 2.22.

2.2.2 Test cubes: 5 cm x 5 cm x 10 cm

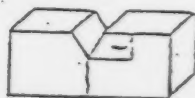
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To determine the specific cutting forces and the compression resistance to the chip, the samples are to be tested as follows and the values measured are to be entered in the table (ref. No. B34 601 sheet 11).

1.1 Measuring the samples

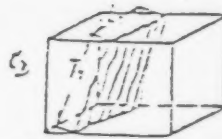
A diagram of a cylinder. A horizontal line across the top circular face is labeled D , representing the diameter. A vertical dashed line from the center of the top face to the center of the bottom face is labeled H , representing the height.

- 1.2 Embedding the sample in a box filled with sand.
- 1.3 In case of bedded material:
Determine direction of bed and make entry in the table in accordance with instructions (see top of sheet 9). Bedded material is to be cut in different directions, if possible.
- 1.4 Placing the pressure wedge in the centre.
- 1.5 Slow loading of the pressure wedge until the sample is separated.
- 1.6 Reading-off the cutting pressure p (bar) at the pressure gauge (maximum pointer).
- 1.7 Determination of the penetration depth t (mm).



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
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- 1.8 Determining the cutting length L_C (mm)
and the cutting depth C_D (mm)



- 1.9 Calculating the cutting area $\lambda_C = L_C \times C_D$

- 1.10 Calculating the cutting force F (KN) by multiplying the indicated cutting-pressure p (bar) with the piston area $\lambda_p = 12.56 \text{ cm}^2$

$$F \text{ (KN)} = p \text{ (bar)} \times \lambda_p (\text{cm}^2) \times 10^{-7}$$

$$F \text{ (KN)} = p \text{ (bar)} \times 0.1256$$

- 1.11 Calculation of the specific cutting forces

F_{LB} (N/cm), P_{LC} (N/cm) and $P_{\lambda C}$ by dividing the breaking force F by the blade length $L_B = 6.5 \text{ cm}$, the cutting length L_C (cm) and the cutting area λ_C (cm²)

$$F_{LB} \text{ (N/cm)} = \frac{F \text{ (KN)}}{L_B \text{ (cm)}} \times 10^3$$

$$P_{LC} \text{ (N/cm)} = \frac{F \text{ (KN)}}{L_C} \times 10^3$$

$$P_{\lambda C} \text{ (N/cm}^2\text{)} = \frac{F \text{ (KN)}}{\lambda_C \text{ (cm}^2\text{)}} \times 10^3$$

- 1.12 To obtain a large number of readings, each sample should, if possible, be cut several times (see sheet 9 below)

Grenzstein & Koppel		Soch-Nr. Ref.No.		I		Sh: 8	
Aktiengesellschaft		834 601					
Date: _____		By: _____		Date: _____		By: _____	

2. Determination of the compressive resistance in one axis

2.1 Determination of the sample area subjected to pressure.

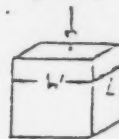
Core sample

$$A = \pi \cdot D^2/4$$



Test tube

$$A = a \times L$$



2.2 Embedding of the sample in the box filled with sand

2.3 Placing the test plate on the test cube

2.4 Slow application of load to the test plate until the sample starts to break.

2.5 Reading-off the pressure at breaking p (bar) at the pressure gauge (maximum pointer).

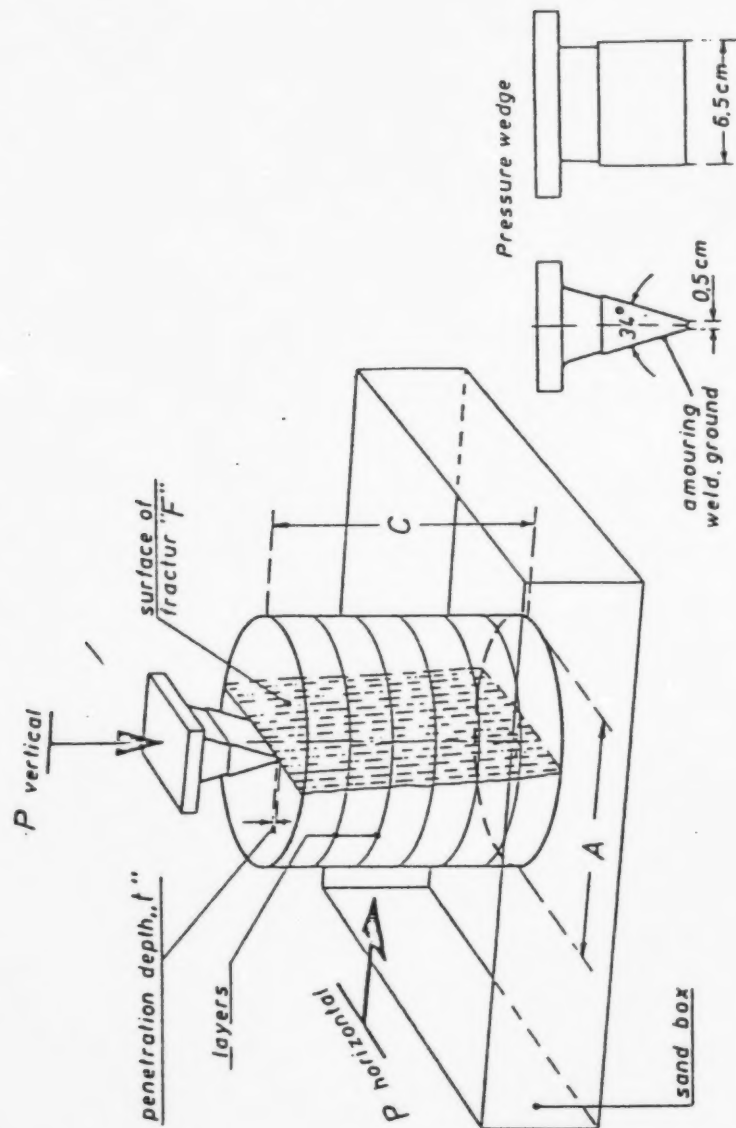
2.6 Calculation of the breaking force analogous to para. 1.10.

2.7 Calculation of the compression resistance in one axis σ_D (N/cm²) by dividing the breaking load F by the area calculated in para. 2.1

$$\sigma_D \text{ (N/cm}^2\text{)} = \frac{F \text{ (N)}}{A \text{ (cm}^2\text{)}} \cdot 10^3$$

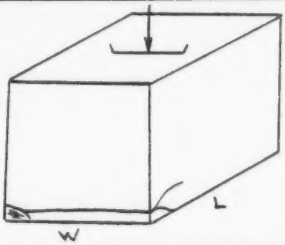
2.8 If the material is bedded, the various samples are to be cut in different directions, if possible.

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Geol. und Bergbau		Datum Name Unters.		Fol. 10	



ORENSTEIN & KOPPEL

JOB NO: A1184

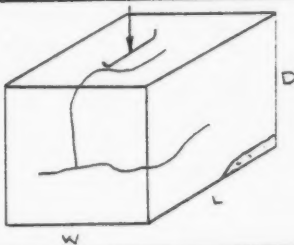
A	SAMPLE		HIGHVALE MINE, Sample 1				
	Material Color Granulation Consistency Inclusions		Siltstone Medium Grey Small fracture at base of Sample				
B	Separation	-					
	Specific mass	$\frac{g}{cm^3}$	2.82				
	Water Content	%	3				
	W x L x D	cm	15.08 x 15.05 x 15.07				
	CUT		1	2 *	3	4	5
C	Separation force	kN	58.541	16.687	36.043	7.565	46.277
	Penetration depth d	cm	0.8	0.5	0.3	0	0
	Blade length L_s	cm	6.5	6.5	6.5	6.5	6.5
	Separation length L	cm	15.1	8.5	15.1	6.5	6.2
	Separation depth D	cm	15.1	15.1	8.3	5.5	8.0
D	Separation area A	cm^2	226.8	127.6	124.6	35.5	49.6
	$\frac{F}{L_s}$	$\frac{N}{cm}$	9002	2567	5545	1164	7120
	$\frac{F}{L}$	$\frac{N}{cm}$	3888	1971	2395	1170	7504
	$\frac{F}{A}$	$\frac{N}{cm^2}$	258	131	289	213	933
E	Remarks *Tends to break along fracture.						

ROCK CUTTING TEST RESULTS

ORENSTEIN & KOPPEL

DATE: December 1980

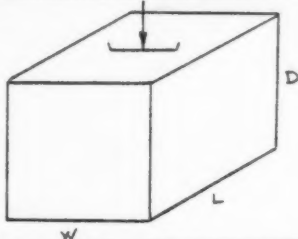
JOB NO: A1184

A	SAMPLE		HIGHVALE MINE, Sample 3					
	Material		Siltstone					
	Color		Medium grey					
	Granulation							
	Consistency							
	Inclusions		Small fractures parallel to bedding					
B	Separation	-						
	Specific mass	$\frac{g}{cm^3}$	2.76					
	Water Content	%	2					
	W x L x D	cm	12.74 x 12.93 x 12.77					
	CUT		1	2	3	4	5	
C	Separation force	kN	60.072*	34.488**	19.579			
	Penetration depth d	cm	0.5	1.2	0.2			
	Blade length L_s	cm	6.5	6.5	6.5			
	Separation length L	cm	12.9	4.1	8.6			
	Separation depth D	cm	12.8	12.8	6.9			
D	Separation area A	cm^2	164.2	52.7	59.9			
	$\frac{F}{L_s}$	$\frac{N}{cm}$	9241	5367	3012			
	$\frac{F}{L}$	$\frac{N}{cm}$	4671	8509	2268			
	$\frac{F}{A}$	$\frac{N}{cm^2}$	366	662	327			
E	Remarks *Tends to break along fractures. **F = 25.806 kN along crack.							

ROCK CUTTING TEST RESULTS

ORENSTEIN & KOPPEL

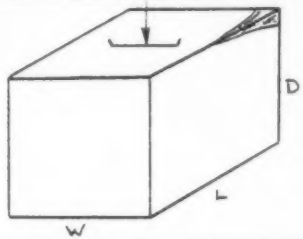
DATE: December 1980
JOB NO: A1184

A	SAMPLE		HIGHVALE MINE, Sample 4				
	Material Color Granulation Consistency Inclusions		Sandstone "Salt & Pepper" grey Fine & medium grained				
B	Separation	-					
	Specific mass	$\frac{g}{cm^3}$	2.13				
	Water Content	%	9				
	W x L x D	cm	15.22 x 15.01 x 14.96				
	CUT		1	2	3	4	5
C	Separation force	kN	2.445	1.602	1.513	1.557	0.445
	Penetration depth d	cm	1.5	1.8	0.7	1.7	0.7
	Blade length L_s	cm	6.5	6.5	6.5	6.5	6.5
	Separation length L	cm	15.2	8.8	15.2	9.3	7.2
	Separation depth D	cm	15.2	15.2	6.3	8.2	6.7
D	Separation area A	cm^2	231.5	133.8	96.0	75.7	48.3
	$\frac{F}{L_s}$	$\frac{N}{cm}$	376	246	233	240	68
	$\frac{F}{L}$	$\frac{N}{cm}$	161	182	99	168	61
	$\frac{F}{A}$	$\frac{N}{cm^2}$	11	12	16	21	9
E	Remarks						

ROCK CUTTING TEST RESULTS

ORENSTEIN & KOPPEL

DATE: December 1980
JOB NO: A1184

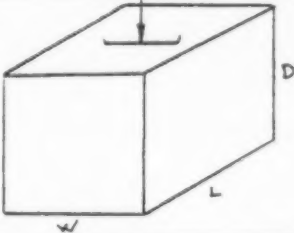
A	SAMPLE		HIGHVALE MINE, Sample 5				
	Material		Siltstone, sandy				
	Color		Medium grey				
	Granulation		Very fine and fine grained				
	Consistency						
	Inclusions						
B	Separation	-					
	Specific mass	$\frac{g}{cm^3}$	2.53				
	Water Content	%	3				
	W x L x D	cm	15.07 x 15.01 x 15.03				
	CUT		1	2	3	4	5
C	Separation force	kN	31.816	22.249	13.794	11.569	7.787
	Penetration depth d	cm	1.2	0.3	0.4	0.1	0.3
	Blade length L_s	cm	6.5	6.5	6.5	6.5	6.5
	Separation length L	cm	12.7	7.7	10.8	7.9	3.8
	Separation depth D	cm	12.6	11.68	6.1	5.1	5.0
D	Separation area A	cm^2	160.7	87.4	66.1	40.0	19.0
	$\frac{F}{L_s}$	$\frac{N}{cm}$	4895	3423	2122	1780	1198
	$\frac{F}{L}$	$\frac{N}{cm}$	2497	2894	1281	1462	2033
	$\frac{F}{A}$	$\frac{N}{cm^2}$	198	255	207	289	410
E	Remarks						

ROCK CUTTING TEST RESULTS

ORENSTEIN & KOPPEL

DATE: December 1980

JOB NO: A1184

A	SAMPLE		HIGHVALE MINE, Sample 6				
	Material		Siltstone, sandy				
	Color		Medium grey				
	Granulation		Very fine and fine grained				
	Consistency						
Inclusions							
B	Separation	-					
	Specific mass	$\frac{g}{cm^3}$	2.38				
	Water Content	%	5				
	W x L x D	cm	15.14 x 15.75 x 15.00				
	CUT		1	2	3	4	5
C	Separation force	kN	23.806	15.797	16.464	26.263*	22.471
	Penetration depth $\bar{d}$	cm	1.0	0.8	1.0	0.6	1.1
	Blade length L_s	cm	6.5	6.5	6.5	6.5	6.5
	Separation length L	cm	15.8	12.7	15.8	10.0	6.9
	Separation depth D	cm	15.0	15.0	10.0	15.8	9.2
D	Separation area A	cm^2	236.3	190.9	158.1	157.3	63.2
	$\frac{F}{L_s}$	$\frac{N}{cm}$	3662	2430	2533	4039	3457
	$\frac{F}{L}$	$\frac{N}{cm}$	1511	1241	1045	2629	3258
	$\frac{F}{A}$	$\frac{N}{cm^2}$	101	83	104	167	356
E	Remarks *Same as cut no. 5.						

ROCK CUTTING TEST RESULTS

ORENSTEIN & KOPPEL

DATE: December 1980
JOB NO: A1184

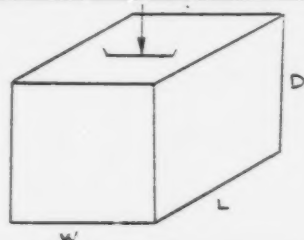
A	SAMPLE		DIPLOMAT MINE, Sample 1				
	Material		Silt till, sandy				
	Color		Dark brown				
	Granulation						
	Consistency						
		Inclusions					
B	Separation	-					
	Specific mass	$\frac{\text{kg}}{\text{cm}^3}$	2.03				
	Water Content	%	10				
	W x L x D	cm	12.95 x 12.31 x 12.35				
	CUT		1	2	3	4	5
C	Separation force	kN	2.136	1.602	1.112	1.513	0.556
	Penetration depth d	cm	1.2	1.4	0	1.4	0
	Blade length L_s	cm	6.5	6.5	6.5	6.5	6.5
	Separation length L	cm	12.9	7.1	11.4	6.6	5.5
	Separation depth D	cm	11.4	11.4	5.4	7.5	5.4
D	Separation area A	cm^2	147.2	81.5	62.1	50.0	29.9
	$\frac{F}{L_s}$	$\frac{\text{N}}{\text{cm}}$	329	246	171	233	86
	$\frac{F}{L}$	$\frac{\text{N}}{\text{cm}}$	166	225	97	228	101
	$\frac{F}{A}$	$\frac{\text{N}}{\text{cm}^2}$	15	20	18	30	19
E	Remarks						

ROCK CUTTING TEST RESULTS

ORENSTEIN & KOPPEL

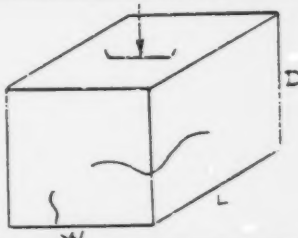
DATE: December 1980

JOB NO: A1184

A	SAMPLE		DIPLOMAT MINE, Sample 2				
	Material		Silt till, Sandy				
	Color		Dark brown				
	Granulation						
	Consistency						
Inclusions							
B	Separation	-					
	Specific mass	$\frac{g}{cm^3}$	2.06				
	Water Content	%	7				
	W x L x D	cm	12.61 x 12.50 x 12.52				
	CUT		1	2	3	4	5
C	Separation force	kN	2.269	1.001	3.026	1.691	0.890
	Penetration depth $\bar{e}$	cm	1.8	1.1	1.3	1.5	0.8
	Blade length L_s	cm	6.5	6.5	6.5	6.5	6.5
	Separation length L	cm	12.5	6.0	9.5	5.9	6.2
	Separation depth D	cm	12.5	12.5	5.6	7.0	6.1
D	Separation area A	cm^2	156.5	75.2	53.2	41.3	38.2
	$\frac{F}{L_s}$	$\frac{N}{cm}$	349	154	466	260	137
	$\frac{F}{L}$	$\frac{N}{cm}$	182	167	318	286	141
	$\frac{F}{A}$	$\frac{N}{cm^2}$	15	13	57	41	23
E	Remarks						

ORENSTEIN & KOPPEL

JOB NO: A1184

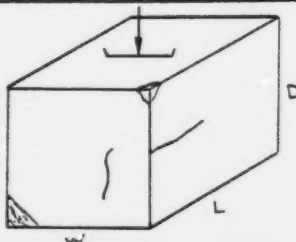
A	SAMPLE		SOURIS VALLEY MINE, Sample 2				
	Material		Claystone				
	Color		Medium grey				
	Granulation						
	Consistency						
Inclusions		A few fractures					
B	Separation	-					
	Specific mass	$\frac{g}{cm^3}$	2.65				
	Water Content	%	1				
	W x L x D	cm	12.81 x 12.92 x 12.91				
	CUT		1	2	3	4	5
C	Separation force	kN	26.031*	29.591	32.483	33.373	8.455
	Penetration depth d	cm	0.2	0.4	0.5	0.1	0.2
	Blade length L_s	cm	6.5	6.5	6.5	6.5	6.5
	Separation length L	cm	12.9	6.4	10.9	5.6	4.6
	Separation depth D	cm	12.9	12.9	6.5	6.8	6.4
D	Separation area A	cm^2	166.8	82.6	71.4	37.9	29.4
	$\frac{F}{L_s}$	$\frac{N}{cm}$	4005	4552	4997	5134	1301
	$\frac{F}{L}$	$\frac{N}{cm}$	2015	4622	2968	5942	1834
	$\frac{F}{A}$	$\frac{N}{cm^2}$	156	358	455	880	288
E	Remarks * Tends to break along fractures.						

ROCK CUTTING TEST RESULTS

ORENSTEIN & KOPPEL

DATE: December 1980

JOB NO: A1184

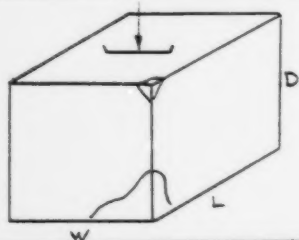
A	SAMPLE		SOURIS VALLEY, Sample 3				
	Material		Claystone				
	Color		Medium grey				
	Granulation						
	Consistency						
	Inclusions		Horizontal and vertical Cracks				
B	Separation	-					
	Specific mass	$\frac{g}{cm^3}$	2.57				
	Water Content	%	1				
	W x L x D	cm	14.02 x 13.82 x 14.70				
	CUT		1	2	3	4	5
C	Separation force	kN	22.916*				
	Penetration depth d	cm	0.1				
	Blade length L_s	cm	6.5				
	Separation length L	cm	14.0				
	Separation depth D	cm	14.7				
D	Separation area A	cm^2	206.1				
	$\frac{F}{L_s}$	$\frac{N}{cm}$	3526				
	$\frac{F}{L}$	$\frac{N}{cm}$	1635				
	$\frac{F}{A}$	$\frac{N}{cm^2}$	111				
E	Remarks *Fractured surfaces precluded further cuts.						

ROCK CUTTING TEST RESULTS

ORENSTEIN & KOPPEL

DATE: December 1980

JOB NO: A1184

A	SAMPLE		SOURIS VALLEY MINE, Sample 4				
	Material		Claystone				
	Color		Medium grey				
	Granulation						
	Consistency						
Inclusions		A few fractures					
B	Separation	-					
	Specific mass	$\frac{g}{cm^3}$	2.49				
	Water Content	%	2				
	W x L x D	cm	14.08 x 13.83 x 13.89				
	CUT		1	2	3	4	5
C	Separation force	kN	30.926*				
	Penetration depth d	cm	0.5				
	Blade length L_s	cm	6.5				
	Separation length L	cm	13.8				
	Separation depth D	cm	13.9				
D	Separation area A	cm^2	192.1				
	$\frac{F}{L_s}$	$\frac{N}{cm}$	4758				
	$\frac{F}{L}$	$\frac{N}{cm}$	2236				
	$\frac{F}{A}$	$\frac{N}{cm^2}$	161				
E	Remarks *Fractured surfaces precluded further cuts.						

ROCK CUTTING TEST RESULTS

ORENSTEIN & KOPPEL

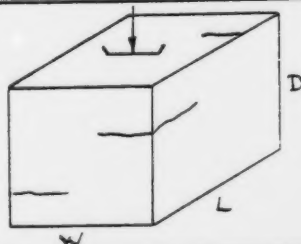
DATE: December 1980

JOE NO: A1184

A	SAMPLE		POPLAR RIVER MINE, Sample 1				
	Material		Siltstone; clayey				
	Color		Light grey				
	Granulation						
	Consistency						
Inclusions		Horizontal and vertical fractures					
B	Separation	-					
	Specific mass	$\frac{g}{cm^3}$	2.03				
	Water Content	%	6				
	W x L x D	cm	17.10 x 15.05 x 17.90				
	CUT		1	2	3	4	5
C	Separation force	kN	4.227*				
	Penetration depth d	cm	1.8				
	Blade length L_s	cm	6.5				
	Separation length L	cm	17.1				
	Separation depth D	cm	17.9				
D	Separation area A	cm^2	306.1				
	$\frac{F}{L_s}$	$\frac{N}{cm}$	650				
	$\frac{F}{L}$	$\frac{N}{cm}$	247				
	$\frac{F}{A}$	$\frac{N}{cm^2}$	14				
E	Remarks *Fractured surfaces precluded further cuts.						

ORENSTEIN & KOPPEL

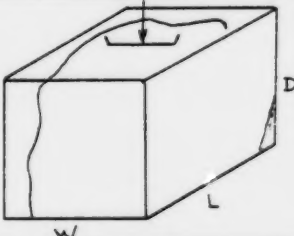
JOB NO: A1184

A	SAMPLE		POPLAR RIVER MINE, Sample 2				
	Material		Siltstone; clayey				
	Color		Light grey				
	Granulation						
	Consistency		Fractures parallel to bedding				
Inclusions							
B	Separation	-					
	Specific mass	$\frac{g}{cm^3}$	1.94				
	Water Content	%	11				
	W x L x D	cm	13.03 x 13.13 x 13.10				
	CUT		1	2	3	4	5
C	Separation force	kN	5.785	3.337	0.667	0.801	1.557
	Penetration depth d	cm	1.0	1.1	0.4	0.8	0.1
	Blade length L_s	cm	6.5	6.5	6.5	6.5	6.5
	Separation length L	cm	13.0	11.0	7.3	5.7	5.6
	Separation depth D	cm	13.1	13.1	13.1	13.1	7.0
D	Separation area A	cm^2	170.3	144.1	95.9	74.6	38.8
	$\frac{F}{L_s}$	$\frac{N}{cm}$	890	513	103	123	240
	$\frac{F}{L}$	$\frac{N}{cm}$	445	303	91	141	281
	$\frac{F}{A}$	$\frac{N}{cm^2}$	34	23	7	11	40
E	Remarks						

ROCK CUTTING TEST RESULTS

ORENSTEIN & KOPPEL

DATE: December 1980
JOB NO: A1184

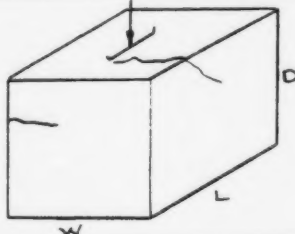
A	SAMPLE		POPLAR RIVER MINE, Sample 3				
	Material		Siltstone Clayey				
	Color		Light grey				
	Granulation						
	Consistency						
	Inclusions		A few fractures				
B	Separation	-					
	Specific mass	$\frac{g}{cm^3}$	1.77				
	Water Content	%	3				
	W x L x D	cm	13.95 x 13.07 x 14.1				
	CUT		1	2	3	4	5
C	Separation force	kN	1.780	1.780	2.336	2.559	0.934
	Penetration depth d	cm	1.2	0.6	0.2	0.3	0.3
	Blade length L_s	cm	6.5	6.5	6.5	6.5	6.5
	Separation length L	cm	13.1	5.4	13.1	10.5	7.0
	Separation depth D	cm	14.1	14.1	7.5	6.1	6.7
D	Separation area A	cm^2	184.3	76.3	97.8	63.5	42.2
	$\frac{F}{L_s}$	$\frac{N}{cm}$	274	274	359	394	144
	$\frac{F}{L}$	$\frac{N}{cm}$	136	329	179	244	133
	$\frac{F}{A}$	$\frac{N}{cm^2}$	10	23	24	40	20
E	Remarks						

ROCK CUTTING TEST RESULTS

ORENSTEIN & KOPPEL

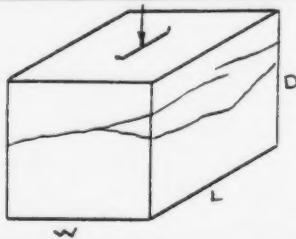
DATE: February 1981

JOB NO: A1184

A	SAMPLE		HIGHVALE MINE, Frozen Sample 1					
	Material		Sandstone					
	Color		light brown grey					
	Granulation		fine and medium grained					
	Consistency							
Inclusions								
B	Separation	-						
	Specific mass	$\frac{g}{cm^3}$	2.102					
	Water Content	%	7.0					
	W x L x D	cm	15.2 x 15.7 x 15.2					
	CUT		1	2	3	4	5	
C	Separation force	kN	33.9	16.0	23.2	10.7	14.7	
	Penetration depth d	cm	1.1	0.5	0.2	0.2	0.1	
	Blade length L_s	cm	6.5	6.5	6.5	6.5	6.5	
	Separation length L	cm	15.7	8.9	15.7	7.9	7.5	
	Separation depth D	cm	15.2	15.2	5.8	9.3	5.3	
D	Separation area A	cm^2	239.1	135.8	91.2	73.5	39.5	
	$\frac{F}{L_s}$	$\frac{N}{cm}$	5215	2461	3569	1646	2262	
	$\frac{F}{L}$	$\frac{N}{cm}$	2159	1797	1478	1354	1960	
	$\frac{F}{A}$	$\frac{N}{cm^2}$	142	118	254	146	372	
E	Remarks Tested at -24°C.							

ORENSTEIN & KOPPEL

JOB NO: A1184

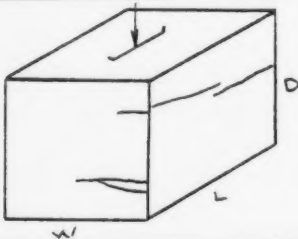
A	SAMPLE		HIGHVALE MINE, Frozen Sample 2a				
	Material		Sandstone "salt and pepper" grey fine and medium grained				
	Color						
	Granulation						
	Consistency						
Inclusions							
B	Separation	-					
	Specific mass	$\frac{g}{cm^3}$	2.502				
	Water Content	%	2.5				
	W x L x D	cm	15.3 x 15.1 x 15.5				
	CUT		1	2	3	4	5
C	Separation force	kN	76.2	49.5	40.1	21	37.9
	Penetration depth d	cm	1.3	1.2	1.2	0.7	1.0
	Blade length L_s	cm	6.5	6.5	6.5	6.5	6.5
	Separation length L	cm	15.1	7.7	15.1	6.1	8.0
	Separation depth D	cm	15.5	15.5	7.9	7.1	8.9
D	Separation area A	cm^2	233.3	120.0	119.0	42.9	71.7
	$\frac{F}{L_s}$	$\frac{N}{cm}$	1172	7615	6169	3230	5830
	$\frac{F}{L}$	$\frac{N}{cm}$	5046	6428	2655	3442	4738
	$\frac{F}{A}$	$\frac{N}{cm^2}$	327	413	337	490	529
E	Remarks Tested at $-24^{\circ}C$.						

ROCK CUTTING TEST RESULTS

ORENSTEIN & KOPPEL

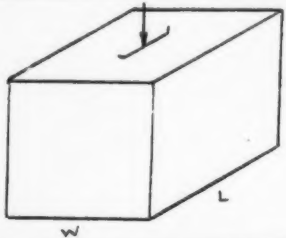
DATE: February 1981

JOB NO: A1184

A	SAMPLE		HIGHVALE MINE, Frozen Sample 2b				
	Material		Sandstone				
	Color		"salt and pepper" grey				
	Granulation		fine and medium grained				
	Consistency						
	Inclusions						
B	Separation	-					
	Specific mass	$\frac{g}{cm^3}$	2.475				
	Water Content	%	2.7				
	W x L x D	cm	15.2 x 15.3 x 15.2				
	CUT		1	2	3	4	5
C	Separation force	kN	53	24.5	17.4	7.1	7.6
	Penetration depth d	cm	1.5	1.4	1.3	0.1	0.6
	Blade length L_s	cm	6.5	6.5	6.5	6.5	6.5
	Separation length L	cm	15.3	7.7	15.3	7.7	5.1
	Separation depth D	cm	15.2	11.2	7.8	5.6	9.0
D	Separation area A	cm^2	232.1	85.5	119.0	43.1	46.1
	$\frac{F}{L_s}$	$\frac{N}{cm}$	8154	3769	2677	1092	1169
	$\frac{F}{L}$	$\frac{N}{cm}$	3464	3181	1137	922	1490
	$\frac{F}{A}$	$\frac{N}{cm^2}$	228	287	146	165	165
E	Remarks Tested at $-6^{\circ}C$.						

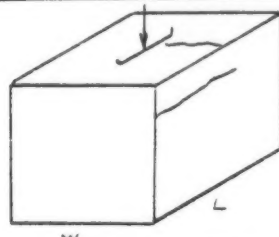
ORENSTEIN & KOPPEL

JOB NO: A1184

A	SAMPLE		HIGHVALE MINE, Frozen Sample 4a					
	Material		Siltstone Medium grey					
	Color							
	Granulation							
	Consistency							
		Inclusions						
B	Separation	-						
	Specific mass	$\frac{g}{cm^3}$	2.669					
	Water Content	%	3.0					
	W x L x D	cm	15.3 x 13.8 x 15.3					
	CUT		1	2	3	4	5	
C	Separation force	kN	149.3	14.7	28.1	29.4	11.1	
	Penetration depth d	cm	1.0	0.8	0.2	0.5	0.1	
	Blade length L_s	cm	6.5	6.5	6.5	6.5	6.5	
	Separation length L	cm	13.8	8.0	13.8	5.9	8.5	
	Separation depth D	cm	15.3	15.3	8.6	8.3	7.0	
D	Separation area A	cm^2	211.0	122.1	119.1	49.4	59.5	
	$\frac{F}{L_s}$	$\frac{N}{cm}$	2296	2261	4323	4523	1708	
	$\frac{F}{L}$	$\frac{N}{cm}$	1081	1838	2036	4983	1306	
	$\frac{F}{A}$	$\frac{N}{cm^2}$	708	120	236	595	187	
E	Remarks Tested at $-24^{\circ}C$.							

ORENSTEIN & KOPPEL

JOB NO: A1184

A	SAMPLE		HIGHVALE MINE, Frozen Sample 4b				
	Material		Siltstone Medium grey				
	Color						
	Granulation						
	Consistency						
	Inclusions						
B	Separation	-					
	Specific mass	$\frac{g}{cm^3}$	2.636				
	Water Content	%	2.2				
	W x L x D	cm	13.9 x 14.0 x 13.5				
	CUT		1	2	3	4	5
C	Separation force	kN	32.5	17.8	25.9	-	19.2
	Penetration depth d	cm	0.7	1.1	0.6	-	0.5
	Blade length L_s	cm	6.5	6.5	6.5	6.5	6.5
	Separation length L	cm	14.0	7.1	13.5	-	5.2
	Separation depth D	cm	13.5	4.5	8.1	-	8.1
D	Separation area A	cm^2	188.6	31.7	109.2	-	42.1
	$\frac{F}{L_s}$	$\frac{N}{cm}$	5000	2738	3985	-	2953
	$\frac{F}{L}$	$\frac{N}{cm}$	2321	2507	1919	-	3692
	$\frac{F}{A}$	$\frac{N}{cm^2}$	172	562	237	-	456
E	Remarks Tested at $-6^{\circ}C$.						

ROCK CUTTING TEST RESULTS

ORENSTEIN & KOPPEL

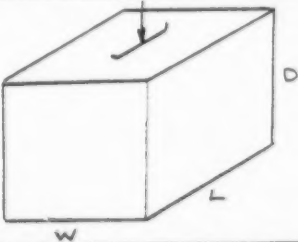
DATE: February 1981
JOB NO: A1184

A	SAMPLE		HIGHVALE MINE, Frozen Sample 5				
	Material		Siltstone				
	Color		Medium grey				
	Granulation						
	Consistency						
	Inclusions						
B	Separation	-					
	Specific mass	$\frac{g}{cm^3}$	2.765				
	Water Content	%	2.0				
	W x L x D	cm	15.3 x 15.3 x 15.3				
	CUT		1	2	3	4	5
C	Separation force	kN	77.1	52.6	40.1	25.9	52.1
	Penetration depth d	cm	1.8	1.0	0.7	0.8	0.3
	Blade length L_s	cm	6.5	6.5	6.5	6.5	6.5
	Separation length L	cm	15.3	9.1	15.3	9.7	8.7
	Separation depth D	cm	15.3	15.3	6.4	9.8	5.4
D	Separation area A	cm^2	234.4	140.1	97.3	94.6	46.7
	$\frac{F}{L_s}$	$\frac{N}{cm}$	1186	8092	6169	3984	8015
	$\frac{F}{L}$	$\frac{N}{cm}$	5039	5780	2621	2670	5988
	$\frac{F}{A}$	$\frac{N}{cm^2}$	329	375	412	274	1116
E	Remarks Tested at $-24^{\circ}C$.						

ROCK CUTTING TEST RESULTS

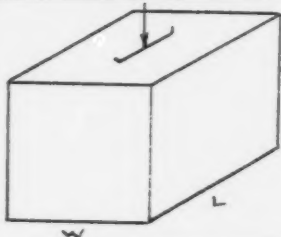
ORENSTEIN & KOPPEL

DATE: February 1981
JOB NO: A1184

A	SAMPLE		WHITEWOOD MINE, Frozen Sample 6				
	Material		Silt, till				
	Color		Medium brown				
	Granulation						
	Consistency						
	Inclusions						
B	Separation	-					
	Specific mass	$\frac{g}{cm^3}$	2.070				
	Water Content	%	15.6				
	W x L x D	cm	15.3 x 14.2 x 15.6				
	CUT		1	2	3	4	5
C	Separation force	kN	25.4	15.6	23.2	18.3	13.8
	Penetration depth d	cm	1.9	1.3	1.9	1.2	1.2
	Blade length L_s	cm	6.5	6.5	6.5	6.5	6.5
	Separation length L	cm	14.2	7.2	14.2	9.5	6.7
	Separation depth D	cm	15.6	15.6	8.9	6.5	8.5
D	Separation area A	cm^2	221.7	112.6	126.3	62.0	57.0
	$\frac{F}{L_s}$	$\frac{N}{cm}$	3908	2400	3569	2815	2123
	$\frac{F}{L}$	$\frac{N}{cm}$	1789	2167	1634	2440	2060
	$\frac{F}{A}$	$\frac{N}{cm^2}$	115	139	184	295	242
E	Remarks Tested at $-24^{\circ}C$.						

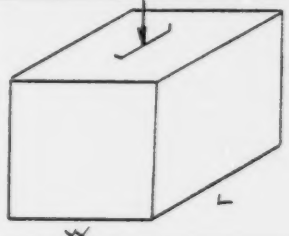
ORENSTEIN & KOPFEL

JOB NO: A1184

A	SAMPLE		WHITEWOOD MINE, Frozen Sample 7				
	Material Color Granulation Consistency Inclusions		Silt, till, clayey Medium grey				
	Separation	-					
	Specific mass	$\frac{g}{cm^3}$	2.095				
	Water Content	%	15.2				
B	W x L x D	cm	16.6 x 15.4 x 15.3				
	CUT		1	2	3	4	5
	Separation force	kN	*				
	Penetration depth d	cm	2.8	2.4	0.4	1.4	1.0
	Blade length L_s	cm	6.5	6.5	6.5	6.5	6.5
C	Separation length L	cm	15.4	8.3	15.4	15.5	8.6
	Separation depth D	cm	15.3	15.3	4.8	12.0	6.8
	Separation area A	cm^2	236.1	127	74.4	186.1	58.8
	$\frac{F}{L_s}$	$\frac{N}{cm}$	5215	3569	1985	2954	2262
	$\frac{F}{L}$	$\frac{N}{cm}$	2201	2795	838	1239	1709
D	$\frac{F}{A}$	$\frac{N}{cm^2}$	144	183	173	103	250
	E Remarks Tested at $-24^{\circ}C$.						

ORENSTEIN & KOPPEL

JOB NO: A1184

A	SAMPLE		WHITEWOOD MINE, Frozen Sample 8				
	Material		Silt, till Medium brown				
	Color						
	Granulation						
	Consistency						
Inclusions							
B	Separation	-					
	Specific mass	$\frac{g}{cm^3}$	2.068				
	Water Content	%	15.6				
	W x L x D	cm	14.8 x 15.4 x 15.0				
	CUT		1	2	3	4	5
C	Separation force	kN	25	21	20.1	21	14.7
	Penetration depth d	cm	2.1	1.8	0.9	1.3	0.7
	Blade length L_s	cm	6.5	6.5	6.5	6.5	6.5
	Separation length L	cm	15.4	8.9	15.0	11.0	7.6
	Separation depth D	cm	15.0	15.0	6.2	9.3	5.3
D	Separation area A	cm^2	231.3	133.2	92.6	102.0	40.2
	$\frac{F}{L_s}$	$\frac{N}{cm}$	3846	3231	3092	3231	2262
	$\frac{F}{L}$	$\frac{N}{cm}$	1623	2360	1340	1909	1934
	$\frac{F}{A}$	$\frac{N}{cm^2}$	108	158	217	206	366
E	Remarks Tested at $-24^{\circ}C$.						

ROCK CUTTING TEST RESULTS

ORENSTEIN & KOPPEL

DATE: February 1981

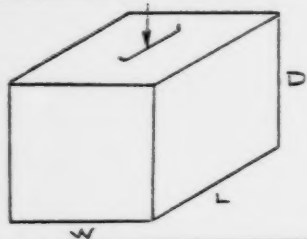
JOB NO: A1184

A	SAMPLE		DIPLOMAT MINE, Frozen Sample 9				
	Material		Silt, till				
	Color		Medium brown				
	Granulation						
	Consistency						
		Inclusions					
B	Separation	-					
	Specific mass	$\frac{\text{g}}{\text{cm}^3}$	1.977				
	Water Content	%	16.1				
	W x L x D	cm	15.4 x 15.3 x 15.3				
	CUT		1	2	3	4	5
C	Separation force	kN	23.6	15.2	10.7	13.8	4.5
	Penetration depth d	cm	1.6	1.0	0.4	0.8	0.2
	Blade length L_s	cm	6.5	6.5	6.5	6.5	6.5
	Separation length L	cm	15.3	9.5	15.3	7.7	7.3
	Separation depth D	cm	15.3	15.3	4.7	9.8	4.6
D	Separation area A	cm^2	234.9	146.2	71.9	75.1	33.6
	$\frac{F}{L_s}$	$\frac{\text{N}}{\text{cm}}$	3631	2339	1646	2123	692
	$\frac{F}{L}$	$\frac{\text{N}}{\text{cm}}$	1543	1600	699	1792	616
	$\frac{F}{A}$	$\frac{\text{N}}{\text{cm}^2}$	101	104	149	184	134
E	Remarks Tested at -24°C .						

ROCK CUTTING TEST RESULTS

ORENSTEIN & KOPPEL

DATE: February 1981
JOB NO: A1184

A	SAMPLE		DIPLOMAT MINE, Frozen Sample 10				
	Material		Silt, till				
	Color		Medium brown				
	Granulation						
	Consistency						
	Inclusions						
B	Separation	-					
	Specific mass	$\frac{g}{cm^3}$	2.142				
	Water Content	%	10.6				
	W x L x D	cm	15.5 x 15.7 x 15.3				
	CUT		1	2	3	4	5
C	Separation force	kN	29.4	28.1	35.2	23.2	20.1
	Penetration depth d	cm	2.2	1.9	2.5	1.7	1.3
	Blade length L_s	cm	6.5	6.5	6.5	6.5	6.5
	Separation length L	cm	15.7	8.6	15.3	8.6	7.8
	Separation depth D	cm	15.3	15.3	6.3	9.1	6.0
D	Separation area A	cm^2	240.8	131.2	97.1	78.1	46.9
	$\frac{F}{L_s}$	$\frac{N}{cm}$	4523	4323	5415	3569	3092
	$\frac{F}{L}$	$\frac{N}{cm}$	1873	3267	2300	2698	2577
	$\frac{F}{A}$	$\frac{N}{cm^2}$	122	214	363	297	429
E	Remarks Tested at -24°C.						

APPENDIX IV

LABORATORY RESULTS - O&K TESTS
FOR CALGARY POWER

Material Received From
Calgary Power Limited.

MATERIAL TESTING

Sampling

To evaluate the effectiveness of the bucket wheel excavator, it is necessary first to determine the cutting resistance of the material that will be excavated. This information can be attained by testing undisturbed samples of various material in the laboratory. It would be very awkward to try and collect large enough samples from the highwall because of its steepness and inaccessibility. It was therefore proposed to obtain block samples from the freshly excavated "chunks" of material that the dragline had recently spoiled. Samples would then be sized, waxed, crated and sent to the laboratory for testing at the end of each day. The selection of samples that were to be tested would then be limited by what was available at the various dragline locations.

If any sandstone or siltstone were encountered, it would be categorized as soft, medium or hard based on infield testing with a Schmidt Rebound Hammer.

There were seven block samples collected from Pit 01 and Pit 02 at the Highvale Mine. Of the seven samples, five were rock obtained from freshly excavated "chunks" of dragline spoil and the remaining two samples were of soils collected approximately two metres below the ground. These samples have been excavated with a backhoe.

The types of location of rock samples taken are shown on the following table:

TABLE 1
SAMPLE TYPES AND LOCATIONS

	<u>Pit 01</u>	<u>Pit 02</u>
Shale	1	1
Soft Sandstone	1	1
Very Hard Sandstone	1	
Silty Till		1
Hard Clayey Silt	1	

The block samples were trimmed to dimensions of approximately 38cm x 38cm x 26 cm, tested with a Schmidt Rebound Hammer or Pocket Penetrometer and then crated and taken to the laboratory for testing. More samples would have been taken but due to limitations imposed by the available budget and the dragline locations, it was decided to proceed with the acquired specimens and after the test results were studied, it would be decided if additional sampling was required.

Test Method

Testing of the soil and rock samples were carried out by Hardy Associates (1978) Limited in accordance with testing procedures detailed by Orenstein & Koppel (O&K). The method of taking and testing soil samples outlined by O&K have been included as Appendix I. The samples that were to be subjected to the wedge and compression tests were first sized; soft samples were cut into cubes and hard samples were cored. The cubed test specimens were approximately 15 cm on each side for the compression tests. The corresponding dimensions of the cylindrical samples varied from a

length to diameter ratio of 1:1 (approximately 15 cm) for the wedge specimens to a 2:1 (approximately 10 cm: 5 cm) for the compression specimens.

In order to approximate winter mining conditions, some of the samples were frozen to -20°C before being tested. A description and distribution of samples that were tested are summarized on Table 2.

Test Results

The results from the laboratory testings were tabulated and forwarded to Mr. Mause of Orenstein & Koppel AG in Lubeck, West Germany (see Tables 305). His analysis of the results indicated that all material except the hard shales and sandstones could be handled by a bucket wheel excavator in their frozen state. Of the samples that were frozen to -20°C , only the very hard silty clays with a moisture content from between 2 and 16 percent could be excavated. All other materials would have to be lightly blasted before loading. It is not known how effectively the rate of mining will limit the amount of frost penetration and therefore the blasting required. Actual field trials would be used to determine what materials could be mined with and without blasting.

APPLICABILITY

Information that is now available for the mine site is very limited. We know the areas of sandstones and shales, but not their degree of hardness. It appears that a bucket wheel excavator can load material that has a cutting resistance value less than 1500 N/cm, the problem is that we do not know what material have a cutting resistance greater than the bucket wheel's capability.

In order to indicate what volume of material may be applicable to a bucket wheel operation at the Highvale Mine, all the material above the first major instance of sandstone (greater than one metre) was outlined (see Plate 2). This material can be excavated during the summer and with controlled blasting during the winter. From the 12 unit mine plan, this total overburden volume is in the order of 800 million bank cubic metres.

Further work, that is site specific, would have to be carried out to determine what material would be handled by the bucket wheel excavator and what material would be left for a dragline. Ideally the dragline would operate on the bottom without rehandle and the bucket wheel excavator would work above with a rate of advance greater than that of the dragline (see Plate 3). This method operation coupled with around the pit conveyors would enable the material to be replaced in the same sequence as it was originally. This is most important from a reclamation point of view.

TABLE 2
HIGHVALE BUCKET WHEEL STUDY
WEDGE AND COMPRESSION SPECIMENS
PREPARED AND TESTED IN THE LAB

Material	Unfrozen		Frozen (-20°C)		Total
	Wedge Specimen	Compression Specimen	Wedge Specimen	Compression Specimen	
Silty Till	2	3	2	3	10
Hard Silty Clay	2	2	2	2	8
Shale	2	2	1	3	8
Soft Sandstone	3	2	1	3	9
Very Hard Sandstone	4	2	2	2	10
				Total	45

TABLE 3

HIGHVALE BUCKET WHEEL STUDY
WEDGE AND COMPRESSION TEST RESULTS

Material	Moisture Content %	Quartz Content %	Cutting Force (KN)		Compressive Resistance (N/cm ²)	
			Unfrozen	Frozen (-20°C)	Unfrozen	Frozen (-20°C)
Silty Till	29.3 30.9	60	Range: 0.13-0.31 Aver: 0.28	Range: 12.6 - 30.14 Aver: 18.64	Range: 10.6 - 10.9 Aver: 12.0	Range: 879-111 Aver: 967
Very Hard Silty Clay	7.1 - 15.1	50	Range: 0.38-0.94 Aver: 0.69	Range: 3.6 - 13.8 Aver: 7.7	Range: 46.5 - 57.4 Aver: 26.0	Range: 538-605 Aver: 572
Shale	6.9 - 7.7	65	Range: 14.2 - 27.4 Aver: 19.8	Range: N/A	Range: N/A	Range: 2103 Aver: 2103
	11.5 - 13.2	40	Range: 2.5 - 5.7 Aver: 4.3	Range: 17.6 - 27.0 Aver: 22.3	Range: 252 - 262.5 Aver: 257.3	Range: 1294- 1481 Aver: 1387.5
Soft Sandstone	11.3 - 11.9	40	Range: 2.5 - 4.8 Aver: 3.7	Range: 36.4 Aver: 36.4	Range: 257 - 381 Aver: 315	Range: 1860- 1870 Aver: 1867.5
	11.1 - 12.6	35	Range: 1.9 - 6.3 Aver: 4.1	Range: N/A Aver:	Range: 16.7 Aver: 16.7	Range: 1135 Aver: 1135
Very Hard Sandstone	1.6 - 1.8	40	Range: 90 - 222 Aver: 153.3	Range: 202 - 209 Aver: 205.5	Range: 9955-11036 Aver: 10495.5	Range: 11195-11 Aver: 11365

TABLE 4
HIGHVALE BUCKET WHEEL STUDY
SPECIFIC CUTTING PRESSURES
UNFROZEN SPECIMENTS

Material	Moisture Content %	Quartz Content %	Pressure per Length of cutting Wedge (N/cm) P_{LB}	Pressure per length of cutting (N/cm) P_{LC}	Pressure per cutting Area (N/cm) P_{AC}	Penetration Depth (cm)
Silty Till	29.3 - 30.9	60	Range: 20-47.7 Aver: 43.1	Range: 19-47.7 Aver: 32.0	Range: 1.3-7.8 Aver: 3.9	Range: 0.15-0.84 Aver: 0.52
Very Hard Silty Clay	7.1 - 15.7	50	Range: 58.5-144.6 Aver: 107.2	Range: 47.9-169.4 Aver: 79.4	Range: 3.2-27.7 Aver: 10.6	Range: 0.25-0.48 Aver: 0.35
Shale	6.9 - 7.7	65	Range: 2738-4212 Aver: 3045	Range: 1597-2706 Aver: 2105	Range: 199.5-272.1 Aver: 226.8	Range: 0.27-0.66 Aver: 0.46
Soft Sandstone	11.5 - 13.2	40	Range: 385-877 Aver: 664.7	Range: 309-591 Aver: 417.6	Range: 27.4-176.7 Aver: 73.0	Range: 0.34-0.51 Aver: 0.43
	11.3 - 11.9	40	Range: 523-738 Aver: 572.2	Range: 207-518 Aver: 340.6	Range: 18.9-58.7 Aver: 40.8	Range: 0.32-0.57 Aver: 0.46
	11.1 - 12.6	35	Range: 292-969 Aver: 632.4	Range: 248-593 Aver: 413	Range: 24.2-74.9 Aver: 43.3	Range: 0.25-1.05 Aver: 0.53
Very Hard Sandstone	1.6 - 1.8	40	Range: 13846-34154 Aver: 26564	Range: 5882-14800 Aver: 9886	Range: 453-1053 Aver: 723.4	Range: 0 Aver: 0

TABLE 5

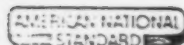
HIGHVALE BUCKET WHEEL STUDY
SPECIFIC CUTTING PRESSURES

-20°C FROZEN SPECIMENS

Material	Moisture Content %	Quartz Content %	Pressure per length of cutting wedge (N/cm) P _{LB}	Pressure per length of cutting length (N/cm) P _{LC}	Pressure per cutting Area (N/cm ²) P _{AC}	Penetration Depth (cm)
Silty Till	29.3 - 30.9	60	Range: 1932-4637 Aver: 2868	Range: 1221-2459 Aver: 1812.7	Range: 107.7-254.3 Aver: 196.6	Range: 0.18-1.52 Aver: 0.53
Very Hard Silty Clay	7.1 - 15.7	50	Range: 587-2123 Aver: 1205.8	Range: 495-948 Aver: 753.1	Range: 47.4-134.1 Aver: 84.9	Range: 0.22-1.18 Aver: 0.53
Shale	6.9 - 7.7 11.5 - 13.2	65 40	N/A Range: 2708-4154 Aver: 3261.5	N/A Range: 1776-2530 Aver: 2237.8	N/A Range: 305.1-365 Aver: 327.9	N/A Range: 0.23-0.55 Aver: 0.38
Soft Sandstone	11.3 - 11.9 11.1 - 12.6	40 35	5600 N/A	2441 N/A	292.6 N/A	0.22 N/A
Very Hard Sandstone	1.6 - 1.8	40	Range: 31077-32154 Aver: 31615.5	Range: 13467-13933 Aver: 13700	Range: 958-1022 Aver: 990	Range: 0 Aver:

APPENDIX V

ASTM D 2938-79 - SPECIFICATIONS
FOR
UNCONFINED COMPRESSION STRENGTH TEST



Standard Test Method for UNCONFINED COMPRESSIVE STRENGTH OF INTACT ROCK CORE SPECIMENS¹

This standard is issued under the fixed designation D 2938; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval.

1. Scope

1.1 This method covers the determination of the unconfined compressive strength of intact cylindrical rock specimens.

NOTE 1—The values stated in U.S. customary units are to be regarded as the standard.

2. Applicable Documents

2.1 *ASTM Standards:*

E 4 Load Verification of Testing Machines²

E 122 Recommended Practice for Choice of Sample Size to Estimate the Average Quality of a Lot or Process³

3. Apparatus

3.1 *Loading Device*, to apply and measure axial load on the specimens, of sufficient capacity to apply load at a rate conforming to the requirements set forth in 5.3. It shall be verified at suitable time intervals in accordance with the procedures given in Methods E 4, and comply with the requirements prescribed therein.

3.2 *Bearing Surfaces*—The testing machine shall be equipped with two steel bearing blocks having a Rockwell hardness of not less than HRC 58 (Note 2). One of the blocks shall be spherically seated and the other a plain rigid block. The bearing faces shall not depart from a plane by more than 0.0005 in. (0.013 mm) when the blocks are new and shall be maintained within a permissible variation of 0.001 in. (0.025 mm). The diameter of the spherically seated bearing face shall be at least as large as that of the test specimen but shall not exceed twice the diameter of the test specimen. The center of the sphere for the spherically seated block shall coincide with the bearing face of the specimen. The movable portion of the bear-

ing block shall be held closely in the spherical seat, but the design shall be such that the bearing face can be rotated and tilted through small angles in any direction.

NOTE 2—False platens, with plane bearing faces conforming to the requirements of this method may be used. These shall consist of disks about $\frac{1}{2}$ to $\frac{3}{4}$ in. (12.7 to 19.05 mm) thick, oil-hardened to more than HRC 58, and surface ground. With abrasive rocks, these platens tend to roughen after a number of specimens have been tested, and hence need to be resurfaced from time to time.

4. Test Specimens

4.1 Test specimens shall be right circular cylinders within the tolerances specified herein. The sides of the specimen shall be generally smooth and free of abrupt irregularities with all elements straight to within 0.020 in. (0.51 mm) over the full length of the specimen. The deviation from straightness of the specimen shall be determined by sitting the cylindrical surface of the specimen on a V-block which is laid flat on a surface. The smoothness of the surface shall not depart from a plane for more than 0.0006 in. (0.015 mm). Mount a dial gage on top of the specimen (Fig. 1) and move the specimen from one end of the specimen to the other along a straight line. Record the maximum and minimum readings on the dial gage and calculate the difference, Δ_0 . Repeat the same operations by rotating the specimen for

¹This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock for Engineering Purposes, and is the direct responsibility of Subcommittee D18.12 on Rock Mechanics.

Current edition approved Jan. 26, 1979. Published April 1979. Originally published as D 2938 - 71. Last previous edition D 2938 - 71a.

²Annual Book of ASTM Standards, Part 41.

³Annual Book of ASTM Standards, Parts 15 and 41.

every 90 deg. and obtain the differences, Δ_{100} , Δ_{150} , and Δ_{270} . The maximum value of these four differences shall be less than 0.020 in.

4.2 Cut the ends of the specimen parallel to each other and at right angles to the longitudinal axis. Grind or lap them (with sanding compounds smaller than 200 grit) until flat to 0.001 in. (0.025 mm). The ends shall not depart from perpendicularity to the axis of the specimen by more than 0.25 deg (approximately 0.01 in. in 2 in. (0.25 in 51 mm)). The perpendicularity of the end surfaces to the longitudinal axis shall be determined by the similar setup as for the cylindrical surface except that the dial gage is mounted near the end of the V block (Fig. 2). Move the mounting pad horizontally so that the dial gage runs across the end surface of the specimen along a diametral direction. Care shall be taken to make sure that one end of the mounting pad maintains intimate contact with the end surface of the V block during moving. Record the dial gage readings and calculate the difference between the maximum and the minimum values, Δ_1 . Rotate the specimen 90 deg and repeat the same operations and calculate the difference Δ_2 . Turn the specimen around and repeat the same measurement procedures for the other end surface and obtain the difference values Δ_1' and Δ_2' . The perpendicularity will be considered to have been met when

$$\frac{\Delta_1}{\text{diameter}} \text{ and } \frac{\Delta_2'}{\text{diameter}} \leq 0.005 \text{ in. (0.13 mm)}$$

where: $i = 1$ or 2. The smoothness of the end surfaces can be determined by taking dial gage readings for every $\frac{1}{8}$ in. (3.2 mm) during the perpendicularity measurements. The closeness of the readings are expected to provide a smooth curve of the end surface along the specific diametral plane. Smoothness requirement is met when the slope along any part of the curve is less than 0.25 deg. The specimen shall have a length-to-diameter ratio (L/D) of 2.0 to 2.5 and a diameter of not less than NX wireline core size, approximately $1\frac{1}{8}$ in. (48 mm). The use of capping materials or end-surface treatments other than the grinding or lapping specified herein is not permitted.

NOTE 3—It is desirable that the diameter of rock compression specimens be at least ten times greater than the diameter of the largest mineral grain. It is considered that the specified minimum specimen diameter of approximately $1\frac{1}{8}$ in. (48 mm) will satisfy

this criterion in the majority of cases. It may be necessary in some instances to test specimens that do not comply with this criterion. In this case, and particularly when cores of diameter smaller than the specified minimum must be tested because of the unavailability of larger size specimens as is often the case in the mining industry, suitable notation of these facts shall be made in the test report.

4.3 Determine the diameter of the test specimen to the nearest 0.01 in. (0.25 mm) by averaging two diameters measured at right angles to each other at about midheight of the specimen. Use this average diameter for calculating the cross-sectional area. The height of the test specimen shall be determined to the nearest 0.01 in. by averaging two height measurements along the diameter.

4.4 The moisture condition of the specimen at time of test can have a significant effect upon the indicated strength of the rock. Good practice generally dictates that laboratory tests be made upon specimens representative of field conditions. Thus it follows that the field moisture condition of the specimen should be preserved until time of test. On the other hand, there may be reasons for testing specimens at other moisture contents including zero. In any case, tailor the moisture content of the test specimen to the problem at hand and report it in accordance with 7.1.7.

5. Procedure

5.1 Check the ability of the spherical seat to rotate freely in its socket before each test.

5.2 Wipe clean the bearing faces of the upper and lower bearing blocks and of the test specimen and place the test specimen on the lower bearing block. As the load is gradually brought to bear on the specimen, adjust the movable portion of the spherically seated block so that uniform seating is obtained.

5.3 Many rock types fail in a violent manner when loaded to failure in compression. A protective shield should be placed around the test specimen to prevent injury from flying rock fragments.

5.4 Apply the load continuously and without shock to produce an approximately constant rate of load or deformation such that failure will occur within 5 to 15 min of loading.

NOTE 4—Results of tests by several investigators have shown that strain rates within this range will provide strength values that are reasonably free of rapid loading effects and reproducible within acceptable tolerances.

6. Calculation

6.1 Calculate the unconfined compressive strength of the specimen by dividing the maximum load carried by the specimen during the test by the cross-sectional area calculated in accordance with 4.3 and express the result to the nearest 10 psi (68.9 kPa).

7. Report

7.1 The report should include the following:

7.1.1 Source of sample including project name and location, and, if known, storage environment. The location is frequently specified in terms of the borehole number and depth of specimen from collar of hole.

7.1.2 Physical description of sample including rock type; location and orientation of apparent weakness planes, bedding planes, and schistosity; large inclusions or inhomogeneities, if any.

7.1.3 Date of sampling and testing.

7.1.4 Specimen diameter and length, conformance with dimensional requirements (see Note 5).

7.1.5 Rate of loading or deformation rate.

7.1.6 General indication of moisture condition of sample at time of test such as as-received, saturated, laboratory air dry, or oven dry. It is recommended that the moisture con-

dition be more precisely determined where possible and reported as either water content or degree of saturation.

7.1.7 Unconfined compressive strength for each specimen as calculated average unconfined compressive strength of all specimens tested, standard deviation or coefficient of variation.

7.1.8 Type and location of failure. A sketch of the fractured sample is recommended.

7.1.9 Other available physical data

NOTE 5—If only cores with a length-to-diameter ratio (L/D) of less than 2 are available, these may be used for the test and this fact noted in the report. However, a length-to-diameter ratio (L/D) as close to 2 as possible should be used. This apparent compressive strength may then be corrected in accordance with the following equation:

$$C = C_a / (0.88 + (0.24b/h))$$

where:

C = computed compressive strength of an equivalent $L/D = 2$ specimen.

C_a = measured compressive strength of the specimen tested.

b = test core diameter as measured in 4.3, and

h = test core height as measured in 4.3.

NOTE 6—The number of specimens tested may depend upon availability of specimens, but normally a minimum of ten is preferred. The number of specimens tested should be indicated. The statistical basis of relating the required number of specimens to the variability of measurements is given in Recommended Practice E 122.

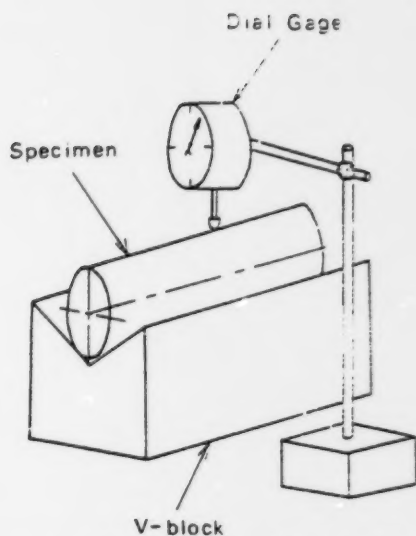


FIG. 1 Assembly for Determining the Straightness of the Cylindrical Surface

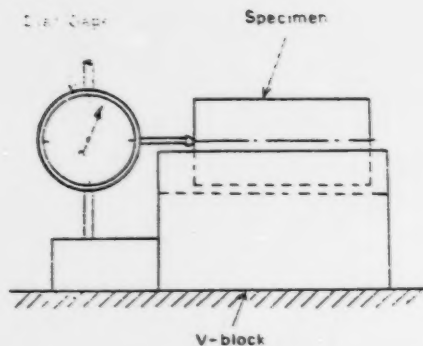


FIG. 2 Assembly for Determining the Perpendicularity of End Surfaces to the Specimen Axis.

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This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, Pa. 19103, which will schedule a further hearing regarding your comments. Failing satisfaction there, you may appeal to the ASTM Board of Directors.

APPENDIX VI

FORTUNA MINE TEST RESULTS

RHEINBRAUN-HAUSMITTEILUNG

Von BT 4	An Betriebsleitung Tagebau Fortuna	Eingangsvermerke
Unsere Zeichen Unsere Nachricht vom <u>2</u> Dr. Wi/mü 27 82	Ihre Zeichen Ihre Nachricht vom	Tag 19.02.1981

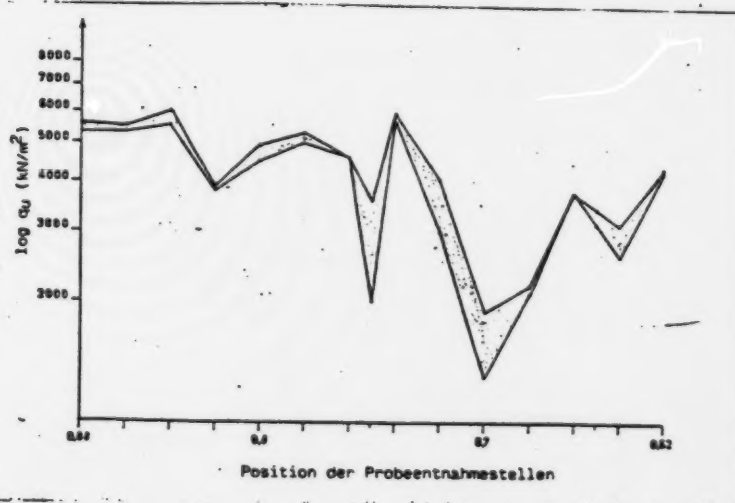
Betrifft:

Tagebau Fortuna, Kohle 7. Sohle, Bg. 201
hier: Einachsiale Druckversuche an quaderförmigen Kohleproben
(Kantenlänge 5cm, Höhe 10 cm, $\lambda = 2$)

In Ergänzung der Probenahme vom 16.01.1981 wurden vereinbarungsgemäß aus dem Hochschnitt der 7. Sohle am 12.02.1981 weitere Kohleproben entnommen und die einachsiale Druckfestigkeit bestimmt (Anlage 1).

Die Festigkeit der Kohle schwankt zwischen $q_{\min} = 1313 \text{ kN/m}^2$ und $q_{\max} = 5966 \text{ kN/m}^2$ (Anlage 2) und liegt im Mittel bei $4059 \pm 1304 \text{ kN/m}^2$.

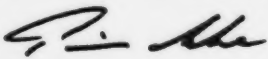
Wie die Versuchsergebnisse zeigen (Abb. 1), liegen die höchsten beobachteten Festigkeitswerte zum Strossenende hin.



- 2 -

Insgesamt nimmt in NE-Richtung die Festigkeit statistisch gesehen ab. Die makroskopisch vermutete hohe Festigkeit xylitreicher Kohle (Probe 38+Holz) hat sich nicht bestätigt.

G l ü c k a u f



D.:

StA, H. Lehmann
Projekt 0060

TRANSLATION TO LETTER DATED FEBRUARY 19, 1981

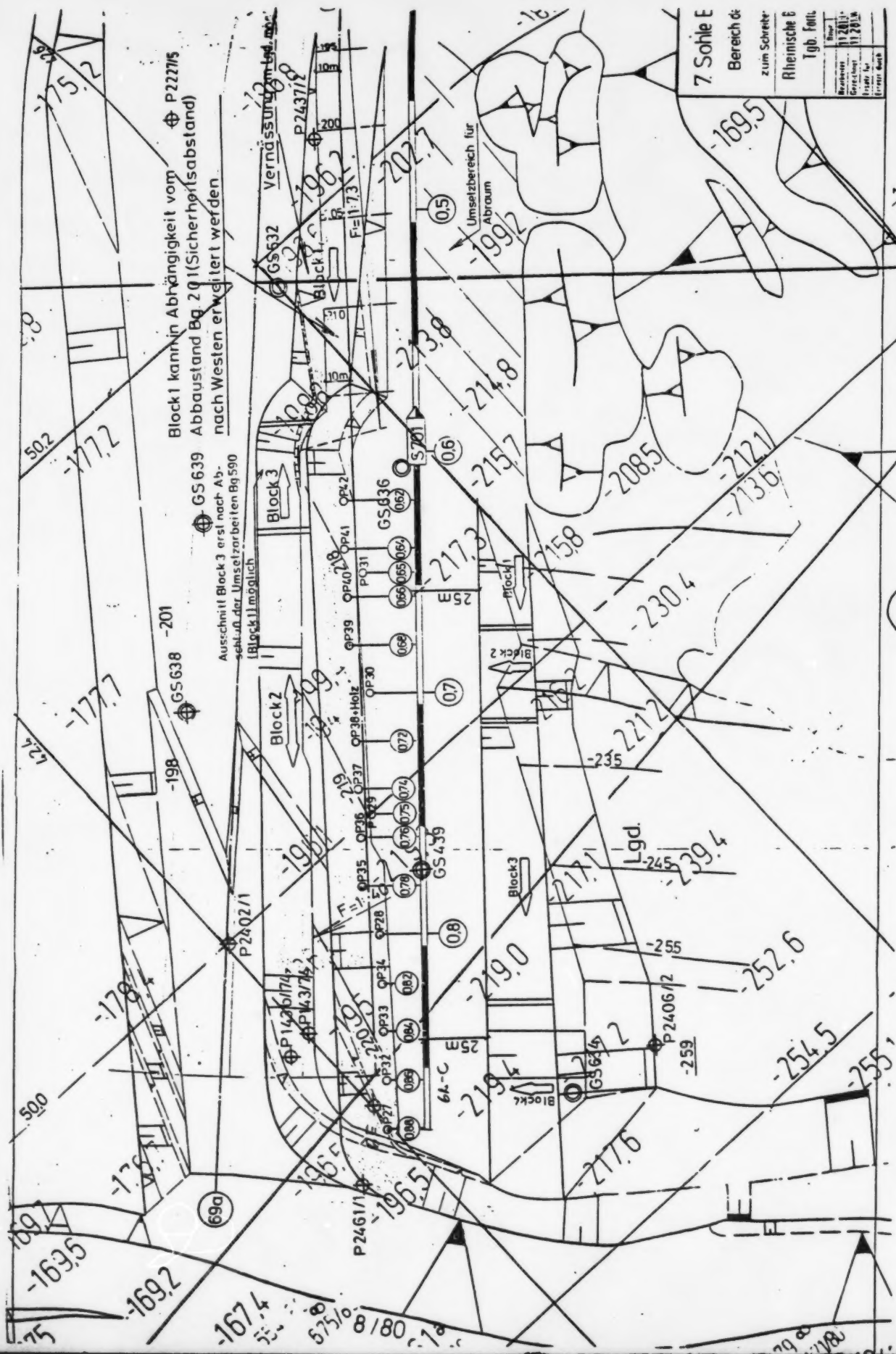
TO: Management of Fortuna Mine

RE: Fortuna Strip Mine, Coal Seam 7, Bench, Bg. 201 as follows: Uniaxial compression test on coal per square area dimensions (L 5cm x 10cm H, $\lambda = 2$). In addition to the sample test taken on January 16, 1981 further samples were taken on February 12, 1981 from the high-cut of Coal Seam #7 and the uniaxial compression strength was determined (Table 1).

The coal strength changes between $q_{u_{min}} = 1818 \text{ kN/m}^2$ and $q_{u_{max}} = 5966 \text{ kN/m}^2$ (Table 2) and an average of $4059 \pm 1304 \text{ kN/m}^2$.

The results are shown in Graph 1. The highest strength value tabulated are at the extreme end of the mining face.

The compression strength of the coal decreases in a northeasterly direction. The assumed high strength of xylolithic coal based on microscopic tests was proven incorrect.



0060

Kohle Tagebau Fortuna, 7. Sohle

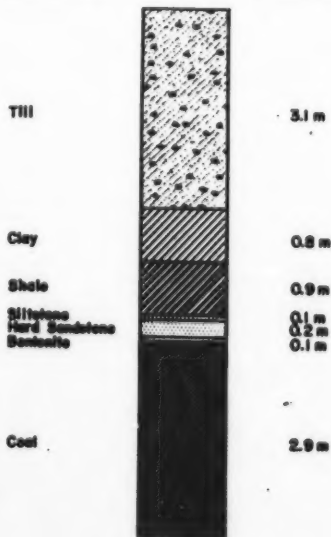
Probe-Nr.	Versuchs-Nr.	Raumwichte γ [kN/m ³]	$\frac{\Delta h}{H}$	Druckfestigkeit [kN/m ²]	Probenserie vom
27	1	11.33	0.027	5252	16.01.1981
	2	11.03	0.031	5622	
32	1	11.26	0.035	5490	12.02.1981
	2	11.20	0.038	5337	
33	1	1155	0.042	5966 max.	
	2	1132	0.040	5475	
34	1	1135	0.024	3824	
	2	1136	0.020	3862	
28	1	10.93	0.020	4864	16.01.1981
	2	10.98	0.024	4524	
35	1	11.33	0.037	5262	12.02.1981
	2	11.22	0.034	5026	
36	1	11.35	0.033	4604	
	2	11.44	0.032	4586	
29	1	11.35	0.015	2012	16.01.1981
	2	11.37	0.020	3628	
37	1	11.08	0.039	5906	12.02.1981
	2	11.46	0.039	5710	
38	1	11.37	0.021	3023	
	2	11.49	0.021	4074	
30	1	11.47	0.009	1313 min.	16.01.1981
	2	11.44	0.010	1905	
39	1	11.11	0.016	2116	12.02.1981
	2	11.45	0.018	2180	
40	1	11.24	0.029	3786	
	2	11.33	0.027	3786	
31	1	11.09	0.025	3440	16.01.1981
	2	11.19	0.022	3169	
41	1	11.44	0.018	3116	12.02.1981
	2	11.32	0.018	2562	
42	1	11.44	0.021	4275	
	2	11.25	0.022	4187	
0		11,30 $\pm$ 0,16	0,026 $\pm$ 0,009	4059 $\pm$ 1304	
Holz (38)	1	10.85	0.020	2517	

APPENDIX VII

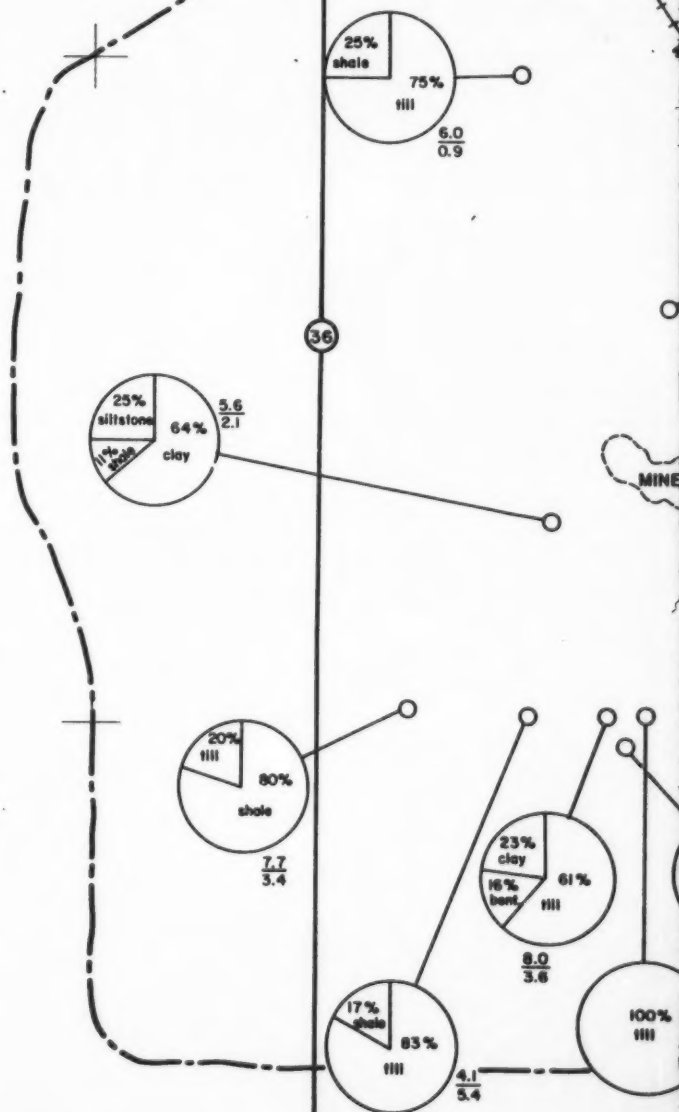
OVERBURDEN TYPE/RATIO MAPS

MATERIAL TYPE

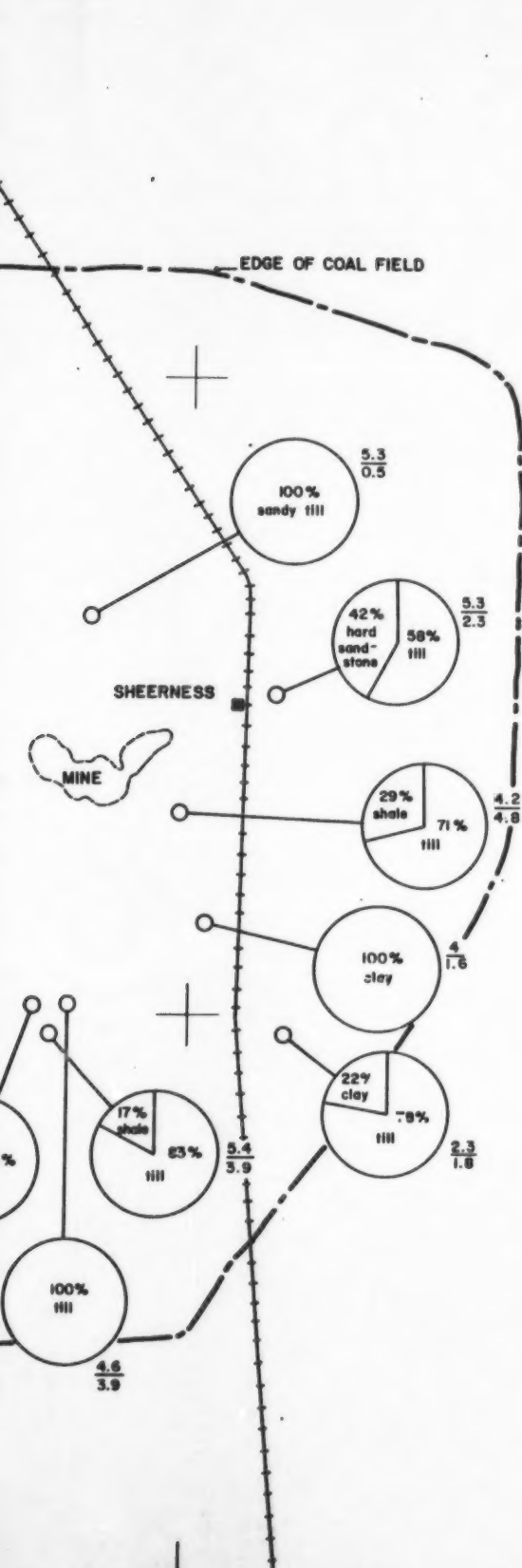
AVERAGE THICKNESS



R 14



R 13

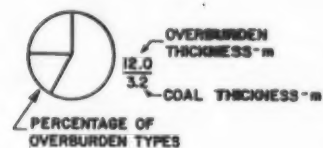


R 12



Tp 30

LEGEND



○ DRILL HOLE

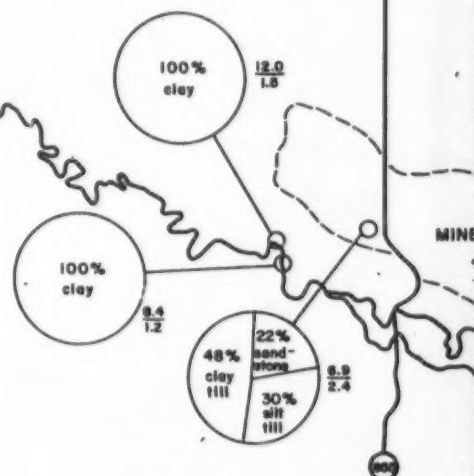
Tp 29

NOTES

- PARTINGS AND/OR INTERBURDEN INCLUDED AS OVERBURDEN.
- LEVEL OF MEASUREMENT SIGNIFICANCE 0.1 metres.

Tp 28

SCALE	1:50000	NTS 72M
CLIENT	CANMET ENERGY MINES AND RESOURCES	
PROJECT	BUCKETWHEEL SELECTION CRITERIA	
TITLE	SHEERNESS MINE	
	GEOCON (1975) LTD.	
PROJECT No.	A1184	DRAWING No. 1
REV		



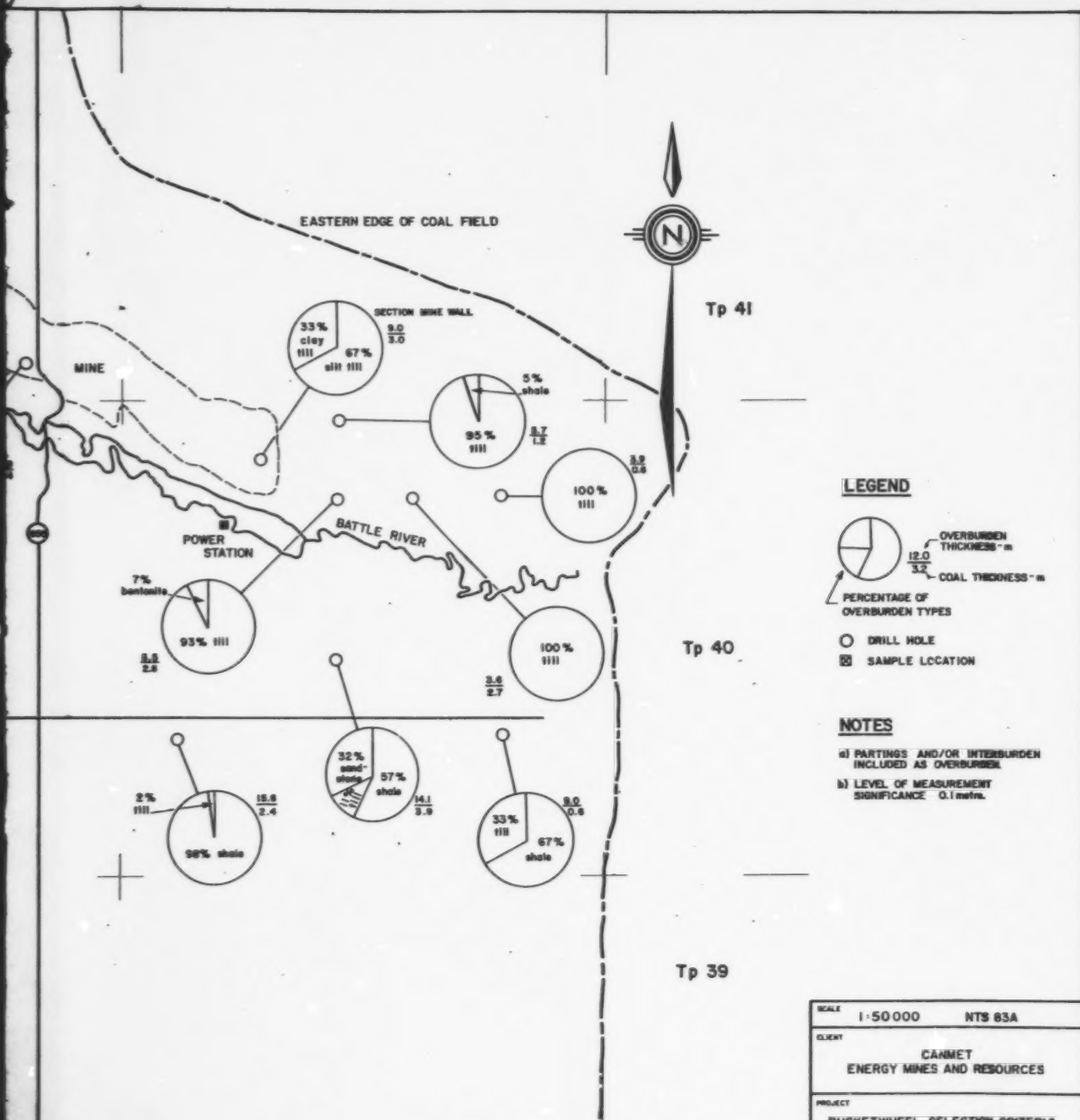
MATERIAL TYPE

AVERAGE THICKNESS

Till	3.4 m
Clay	1.7 m
Soft Sandstone	0.5 m
Shale	2.6 m
Bentonite	0.3 m
Coal	2.0 m

R 17

R 16



SCALE	1:50 000	NTS 83A
CLIENT	CANMET ENERGY MINES AND RESOURCES	
PROJECT	BUCKETWHEEL SELECTION CRITERIA	
TITLE	DIPLOMAT MINE	
GEOCON (1975) LTD.		
PROJECT No.	A1184	Drawing No. 2

MATERIAL TYPE

AVERAGE THICKNESS

Till

10.8 m

Claystone

8.8 m

Sandstone

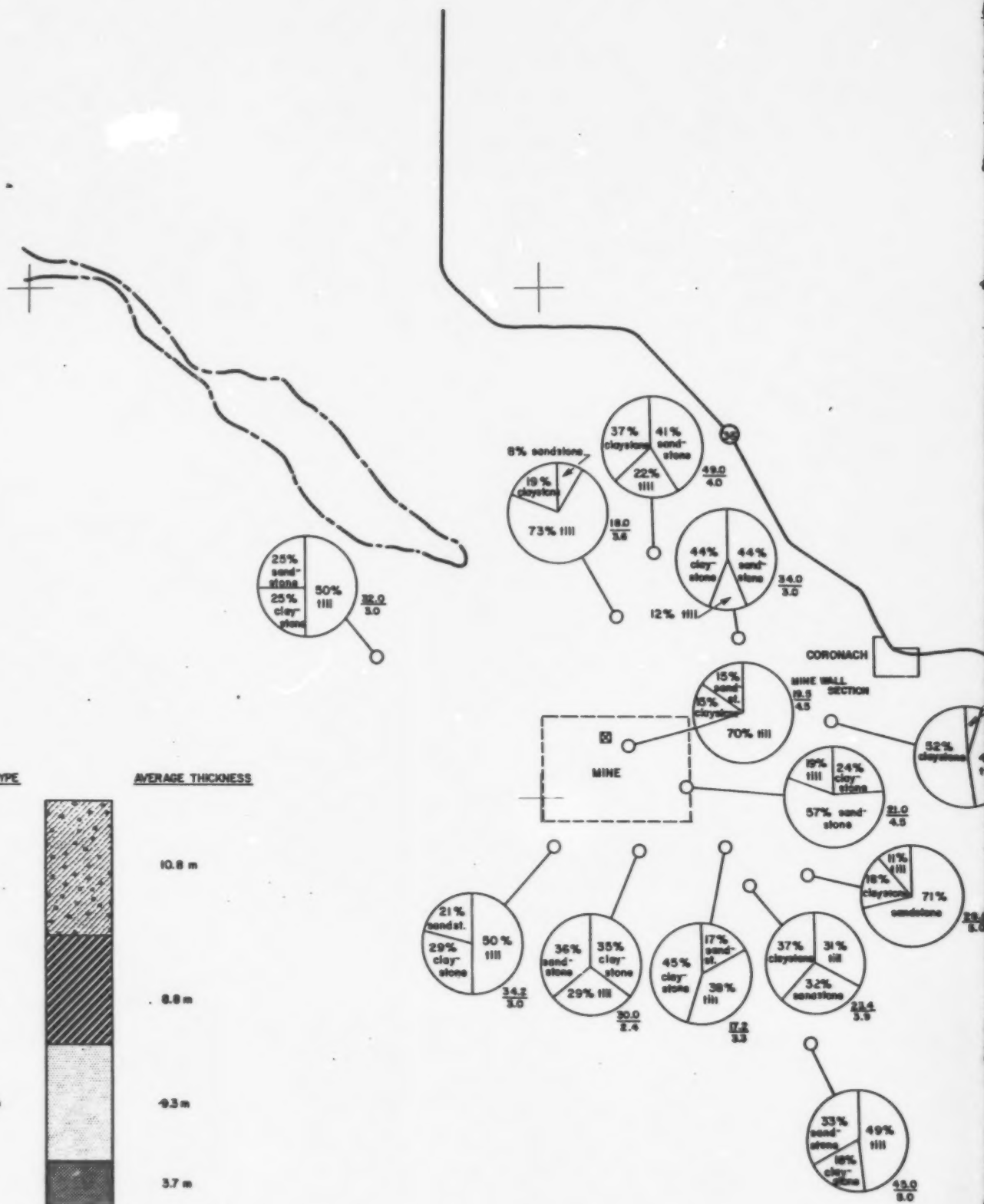
9.3 m

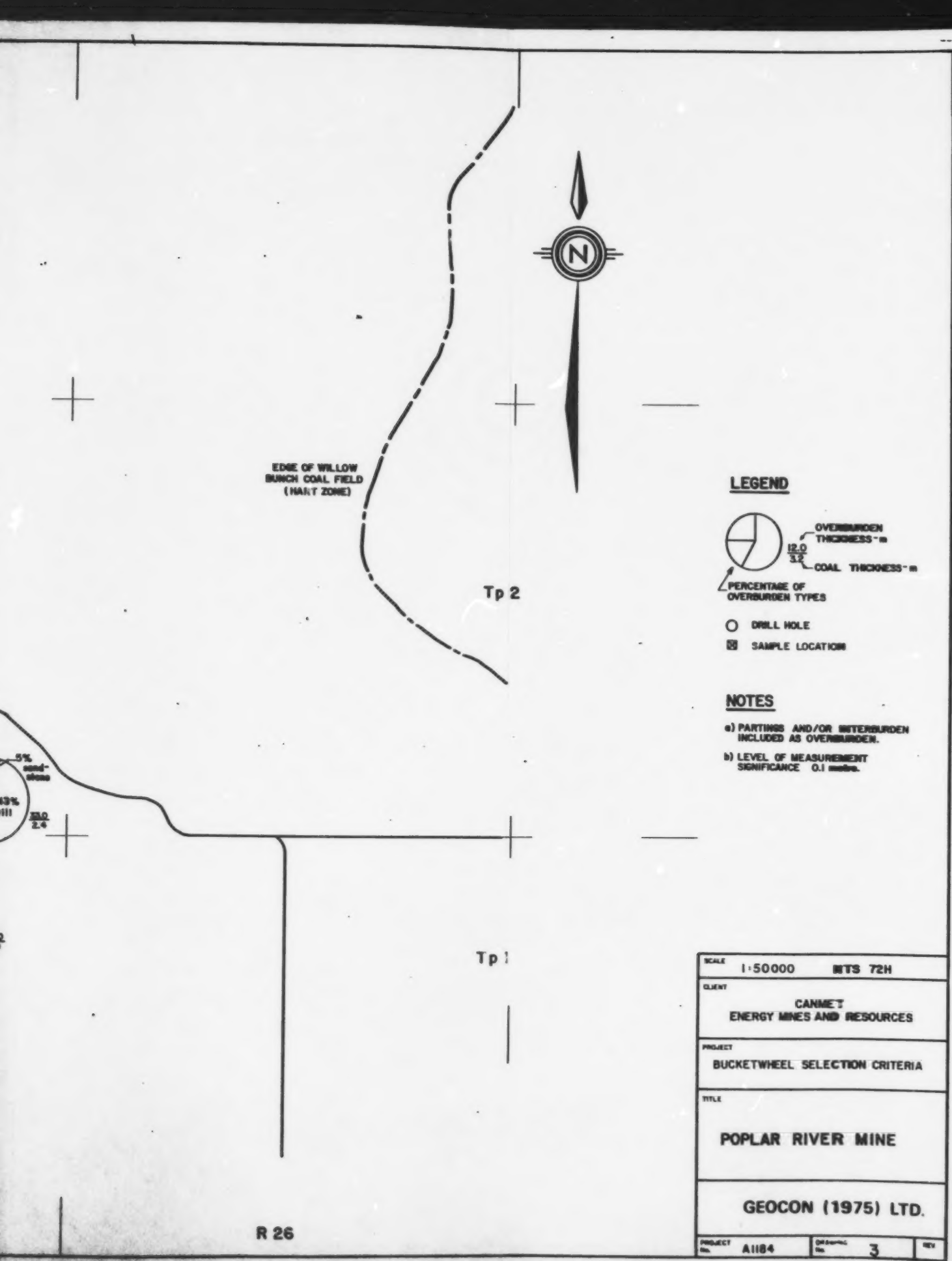
Coal

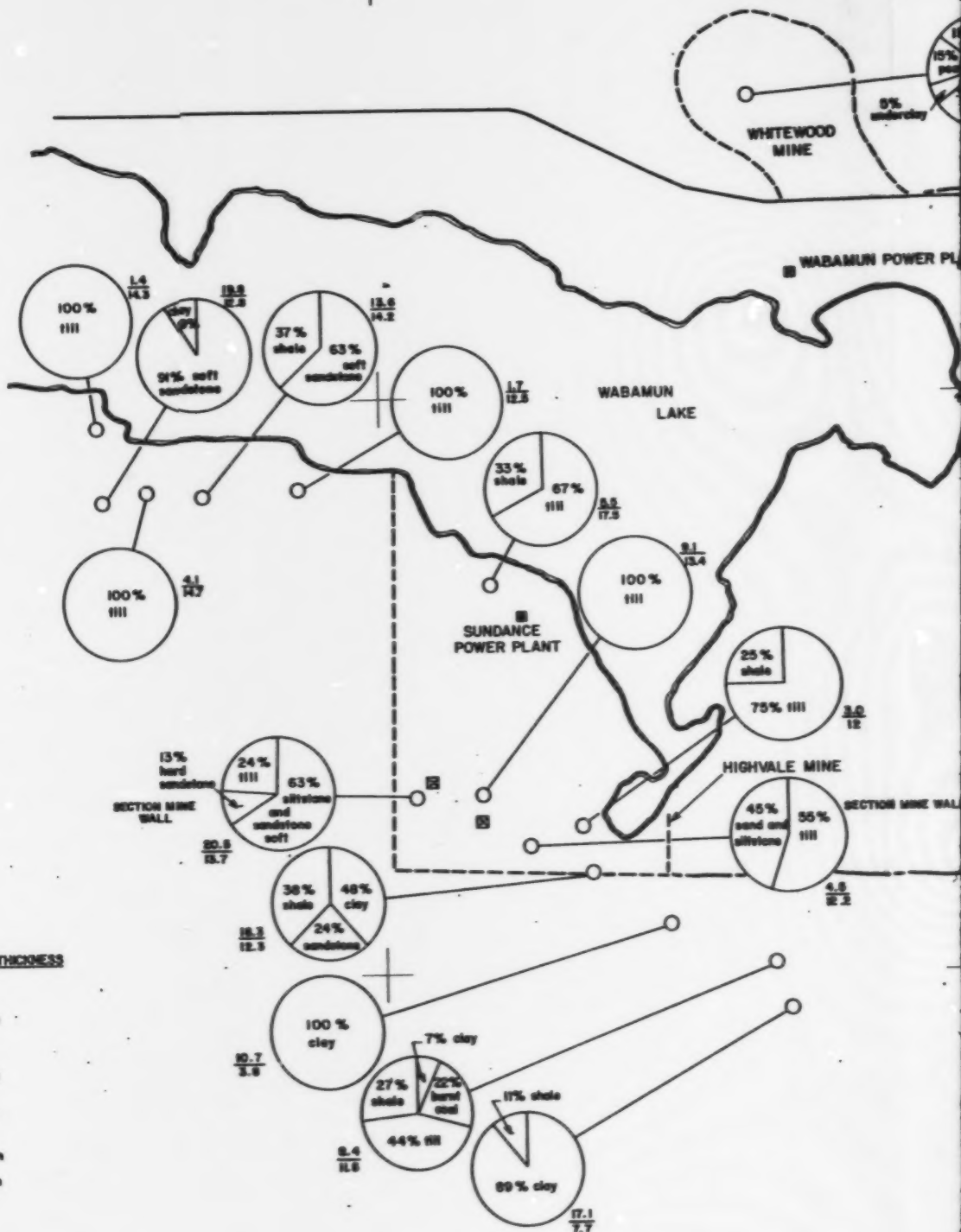
3.7 m

R 28

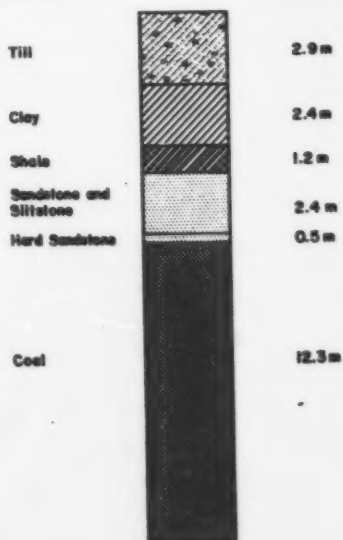
R 25

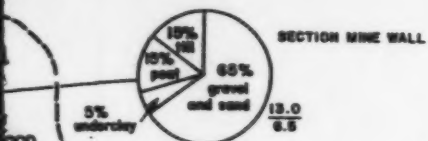






HIGHVALE MINE
MATERIAL TYPE **AVERAGE THICKNESS**





WABAMUN POWER PLANT

3.0
12

SECTION MINE WALL

4.5
12.2

EASTERN EDGE OF
WABAMUN COAL FIELD

SASKATCHEWAN RIVER

R3

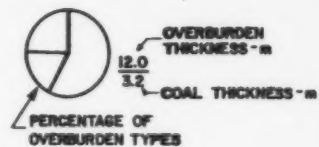


Tp 53

Tp 52

Tp 51

LEGEND



- ☐ DRILL HOLE
- ☒ SAMPLE LOCATION

NOTES

- a) PARTINGS AND/OR INTERBURDEN INCLUDED AS OVERBURDEN.
- b) LEVEL OF MEASUREMENT SIGNIFICANCE 0.1 metre.

SCALE	1:50 000		NTS 83G	
CLIENT	CANMET ENERGY MINES AND RESOURCES			
PROJECT	BUCKETWHEEL SELECTION CRITERIA			
TITLE	WHITEWOOD AND HIGHVALE MINES			
GEOCON (1975) LTD.				
PROJECT No.	A1184	DRAWING No.	4	REV.



EDGE OF ESTEVA
COAL FIELD

ESTEVAN

MATERIAL TYPE

AVERAGE THICKNESS

Till

4.0m

Claystone / Shale

9.4m

Hard Siltstone

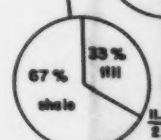
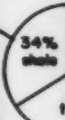
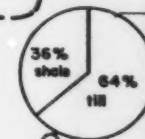
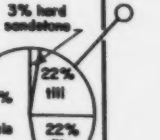
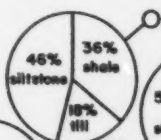
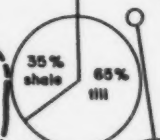
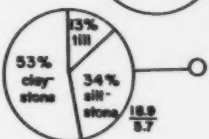
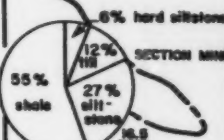
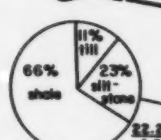
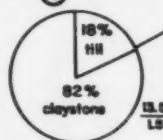
0.2m

Siltstone

3.1m

Coal

3.6m



MINE

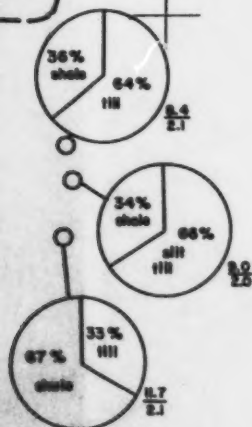
SECTION MINE

EDGE OF ESTEVAN
COAL FIELD

ESTEVAN

SECTION MINE WALL

NE

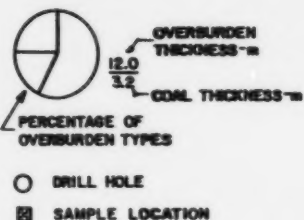


BENFAIT

Tp 2

Tp 1

LEGEND



NOTES

- PARTINGS AND/OR INTERBURDEN INCLUDED AS OVERBURDEN.
- LEVEL OF MEASUREMENT SIGNIFICANCE 0.1 metre.

SCALE	1:50000		NTS 62E	
CLIENT	CANMET ENERGY MINES AND RESOURCES			
PROJECT	BUCKETWHEEL SELECTION CRITERIA			
TITLE	SOURIS VALLEY MINE			
GEOCON (1975) LTD.				
PROJECT No.	A1184	DRAWING No.	5	REV.

R 7